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AUTOMOBILE ENGINE CONTROL PARAMETERS STUDY

VOLUME II: STATUS OF FOREIGN ENGINE CONTROL PRACTICES

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16. Abstract

This report contains the results of a study to evaluate automobile engine control parameters and their effects on vehicle fuel economy and emissions.

Volume I presents detailed technical information on the engine control practices used by selected domestic vehicle manufacturers to meet past and current emission standards, and their own fuel economy, performance and driveability objectives. Volume II treats selected foreign manufacturers. The principal topics reviewed for the twenty-eight engines selected for study are engine design modifications, intake system, carburetion, ignition system, emission control devices and fuel economy effects.

Also included is a discussion of the operational characteristics and design features of engine control hardware, systems, and techniques, and their general implications on fuel economy and emissions.

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PREFACE

This report, prepared by The Aerospace Corporation for the U.S. Department of Transportation, Transportation Systems Center, summarizes the results of an evaluation of automobile engine control parameters and their effects on vehicle fuel economy and emissions. The technical base for this assessment is derived from a comprehensive review of current information on automobile engine operation and performance.

A total of 28 domestic and foreign spark ignition automobile engines in the 40 to 150 horsepower output range were examined in this study, covering the time period from early emission control years through the 1976 model year. The control devices and techniques examined include engine modifications, carburetor, fuel injection, intake system, ignition system, exhaust gas recirculation, and exhaust aftertreatment.

This report is organized in two volumes, Volume I, provides a brief synopsis of study findings, highlighting the significant features and effects of each control technique examined. In addition, it presents (1) a review of the design features and operational characteristics of the engine control approaches employed by the domestic and foreign automobile industry, and (2) a detailed examination of the control techniques incorporated in the selected domestic engines, with particular emphasis on the effects of control system modifications on vehicle fuel economy and emissions.

This volume, Volume II, provides a detailed characterization of the control approaches used in the selected foreign engines.

Appreciation is acknowledged for the guidance and continued assistance provided by Herbert Gould of the U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, who served as the Department of Transportation Project Officer for this study. Appreciation is also extended to K.S. Stacey and M.F. Addonizio of the Environmental Protection Agency, Ann Arbor, Michigan, and to

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The following technical personnel of The Aerospace Corporation contributed to the effort performed under this contract.

W. U. Roessler
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A. Muraszew

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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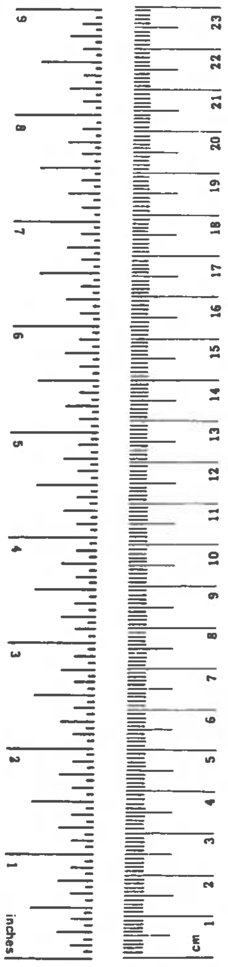
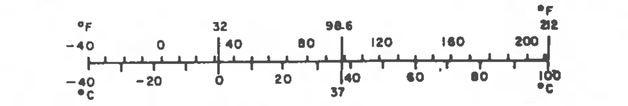
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

Volume II

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ILLUSTRATIONS (Continued)

LIST OF SYMBOLS AND ABBREVIATIONS

A	automatic transmission
AAP	auxiliary acceleration pump
AAPS	Advanced Automotive Power Systems
ABC	after bottom center
ABPV	air bypass valve
A/C	air conditioning
ACV	air control valve
AEEP	Automotive Energy Efficiency Program (DOT)
A/F	air/fuel ratio
AIC	automatic idle control
AIR	air injection reactor
AMC	American Motors Corporation
ASV	air switching valve
ATC	after top center
AVSAC	automatic vehicle speed spark advance control
BBC	before bottom center
BCDV	boost-controlled deceleration valve
BID	breakerless inductive discharge
BPS	backpressure sensor
BTC	before top center
CAIR	converter air injection reactor
CAP	clean air package
CAT	catalyst
CCSA	coolant-controlled spark advance
CCEGR	coolant-controlled exhaust gas recirculation
CCIE	coolant-controlled idle enrichment
CCS	Controlled Combustion System
CCV	closed crankcase ventilation
cfm	cubic feet per minute
CID	cubic inch displacement
CIS	continuous injection system
CO	carbon monoxide

COP	choke opener
COS	cutoff switch
CR	compression ratio
CTO	coolant temperature override
CWS	catalyst warning system
DOT	Department of Transportation
DVDV	differential valve delay valve
EARV	emergency air relief valve
EFE	early fuel evaporation
EGR	exhaust gas recirculation
EM	engine modification
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ESA	electronic spark advance
EVAP	evaporative control system
FDV	fuel deceleration valve
FI	fuel injection
FTP	Federal Test Procedure
GM	General Motors Corporation
HC	hydrocarbon
HEI	high energy ignition
Hg	mercury
IMCO	improved combustion emission control
LTR	lean thermal reactor
M	manual transmission
MC	mixture control
mpg	miles per gallon
NA	not available
NO_x	oxides of nitrogen
OD	overdrive
OHC	overhead cam
OHV	overhead valve

ORI	octane requirement increase
OSAC	orifice spark advance control
PCV	positive crankcase ventilation
PO	pulloff (switch)
PVS	ported vacuum system
rpm	revolutions per minute
RTR	rich thermal reactor
SDV	spark delay valve
TAV	temperature-activated vacuum
TCS	transmission controlled spark
TIDC	thermostatic ignition distributor vacuum control
TIV	thermactor idle dump valve
TOCS	throttle opener control system
TR	thermal reactor
TSP	throttle solenoid positioner
TSC	Transportation Systems Center (DOT)
TVS	thermal vacuum switch
TVSV	thermo-vacuum switch valve
V	venturi
VDV	vacuum differential valve
VSV	vacuum switching valve
VTV	vacuum transmitting valve
WOT	wide open throttle

5. STATUS OF FOREIGN AUTOMOBILE ENGINE CONTROL PRACTICES

This section of the report describes the control systems and techniques used by selected foreign automobile manufacturers to meet current and past emission regulations and examines the effects of engine subsystem calibration modifications implemented during the past several years on vehicle fuel economy and emissions. The manufacturers considered include Audi, BMW, British Leyland, Fiat, Mercedes Benz, Nissan, Peugeot, Saab, Toyota, Volkswagen, and Volvo.

5.1 AUDI

5.1.1 Engine/Vehicle Configurations

Engines of 97- and 114-cubic inch displacement (CID) represent the Audi approach to engine control. The former unit powers the Audi 80, which is known as the Audi Fox in the United States, and the larger unit is the powerplant for the Audi 100. As the smaller engine was introduced in 1975, only the 1975 and 1976 model years are studied. In the case of the larger and older engine, introduced in 1972, the model years of interest are 1972 and 1974-1976.

The 97-CID Audi Fox is rated at 2500-pounds inertia weight and is offered with an automatic three speed and a manual four speed transmission. Both two and four door sedans as well as a station wagon are available. The Audi 100 with the 114-CID engine is placed in the 3000-pound inertia weight class, and the transmission choices are the same as for the Audi Fox. Two and four door sedans are offered.

5.1.2 Engine Design Features

Tables 5-1 and 5-2 present engine design particulars of the two engines (Refs. 5-1 through 5-7). The 97-CID engine is an overhead cam, 4-cylinder unit of modern design, while the 114-CID engine has an overhead valve, pushrod design. Both engines are equipped with the Bosch K Jetronic fuel injection system for 1975 and 1976; however, the larger engine is fitted with a single two venturi carburetor prior to the 1975 model year.

TABLE 5-1. ENGINE SPECIFICATIONS: AUDI 97-CID ENGINE

Engine Parameter	Model Year			
	1976		1975	
	49 States	California	49 States	California
No. of Cylinders	4		4	
Bore, in.	3.13		3.13	
Stroke, in.	3.15		3.15	
Displacement, cu in.	97		97	
Surface/Volume, 1/in.	5.48		5.48	
Compression Ratio	8.0		8.0	
Cylinder Head Type	OHC		OHC	
Advertised HP at Engine Speed, rpm	79 at 5500	77 at 5500	81 at 5800	79 at 5800
Torque, ft-lb, at Engine Speed, rpm	89 at 3300	89 at 3300	90 at 3300	90 at 3300
Exhaust System Type	Single		Single	
Combustion Chamber Configuration	Disc in cylinder head		Disc in cylinder head	
Intake Valve Diameter, in.	1.34		1.34	
Intake Valve Lift, in.	0.406		0.406	
Exhaust Valve Diameter, in.	1.22		1.22	
Exhaust Valve Lift, in.	0.406		0.406	
Intake Valve Opens, deg BTC	4		4	
Intake Valve Closes, deg ABC	46		46	
Intake Valve Duration, deg	230		230	
Exhaust Valve Opens, deg BBC	44		44	
Exhaust Valve Closes, deg ATC	6		6	
Exhaust Valve Duration, deg	230		230	
Valve Overlap, deg	10		10	
Distributor Type	Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance	
Basic Ignition Advance, deg ATC at Engine Speed, rpm	3 at 925		3 at 925	
Idle Speed, rpm	925		925	
Fast Idle Speed, rpm				
Intake Air Temperature Control	None		None	
Fuel System Type	Continuous FI		Continuous FI	
Fuel Metering Method	Fuel flow regulated by air flow		Fuel flow regulated by air flow	
Enrichment Method	Temperature-regulated fuel pressure		Temperature-regulated fuel pressure	
Choke Type				
Carburetor Venturi Diameter, in.				
Maximum Air Flow, cfm	160		160	
Emission Control Systems	EM EVAP FI PCV EGR EM EVAP FI PCV	CAT EGR EM EVAP FI PCV	EGR EM EVAP FI PCV AIR EGR EM EVAP FI PCV	CAT EGR EM EVAP FI PCV
Emission Control Devices	A/C vacuum retard COS Coolant EGR COS[a] Coolant vacuum advance COS[b] Intake manifold vacuum limiter[c]		A/C vacuum retard COS Coolant EGR[a] Coolant vacuum advance COS[b] Intake manifold vacuum limiter[c]	

[a] Vehicles with EGR only

[b] California vehicles only

[c] Manual transmission only

TABLE 5-2. ENGINE SPECIFICATIONS: AUDI 114-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4	
Bore, in.	3.31		3.31		3.31		3.31	
Stroke, in.	3.32		3.32		3.32		3.32	
Displacement, cu in.	114.5		114.5		114.2		114.2	
Surface/Volume, 1/in.	5.16		5.16		-		-	
Compression Ratio	8.0		8.0		8.2		8.5	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	92 at 5500	-	95 at 5500	93 at 5200	91 at 5200		120 at 5600	110 at 5500
Torque, ft-lb, at Engine Speed, rpm	106 at 3200	106 at 3200	109 at 3000	109 at 3000	111 at 3500		120 at 3200	110 at 3200
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Bowl in piston		Bowl in piston		Bowl in piston		Bowl in piston	
Intake Valve Diameter, in.	1.5		1.5		1.5		-	
Intake Valve Lift, in.	0.411		0.411		0.411		-	
Exhaust Valve Diameter, in.	1.3		1.3		1.3		-	
Exhaust Valve Lift, in.	0.411		0.411		0.411		-	
Intake Valve Opens, deg BTC	5		5		5		-	
Intake Valve Closes, deg ABC	37		37		37		-	
Intake Valve Duration, deg	222		222		222		-	
Exhaust Valve Opens, deg BBC	39		39		39		-	
Exhaust Valve Closes, deg ATC	3		3		3		-	
Exhaust Valve Duration, deg	222		222		222		-	
Valve Overlap, deg	8		8		8		-	
Distributor Type	Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance	
Basic Ignition Advance, deg ATC, at Engine Speed, rpm	6 at 925		6 at 925		6 at		8 at	
Idle Speed, rpm	925		925		-		-	
Fast Idle Speed, rpm	-		-		-		-	
Intake Air Temperature Control	None		None		Thermostatic		-	
Fuel System Type	Continuous FI		Continuous FI		2V carburetor		2V carburetor	
Fuel Metering Method	Fuel flow regulated by air flow		Fuel flow regulated by air flow		Fixed orifice		-	
Enrichment Method	-		-		-		-	
Choke Type	Temperature-regulated fuel pressure		Temperature-regulated fuel pressure		Automatic		-	
Carburetor Venturi Diameter, in.	-		-		0.948/1.1		-	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	177 at		177 at		150 at 7		-	
Emission Control Systems	EGR EM EVAP FI PCV	CAT EGR EM EVAP FI PCV	EGR AIR EM EGR EVAP EM FI EVAP PCV FI PCV	CAT EGR EM EVAP FI PCV	AIR EGR EM EVAP PCV		EM EVAP PCV	
Emission Control Devices	A/C vacuum retard COS Coolant EGR COS		A/C vacuum retard COS Coolant EGR COS Coolant vacuum advance COS		A/C vacuum retard COS Coolant vacuum advance COS Intake manifold vacuum limiter		-	

5.1.3 Audi 97-CID Engine

5.1.3.1 Engine Modifications

As the 97-CID engine has been in existence for only two model years, essentially no changes have been made to the original design. The compression ratio is set at 8.0:1 for knock-free operation with 91 octane gasoline and for oxides of nitrogen (NO_x) control. A fairly low surface-to-volume ratio of 5.48 in^{-1} is used to minimize quench area and the formation of unburned hydrocarbons (HC). Intake-exhaust valve overlap is low at 10 deg since EGR is used as the primary method of achieving intake charge dilution for control of NO_x.

5.1.3.2 Intake System

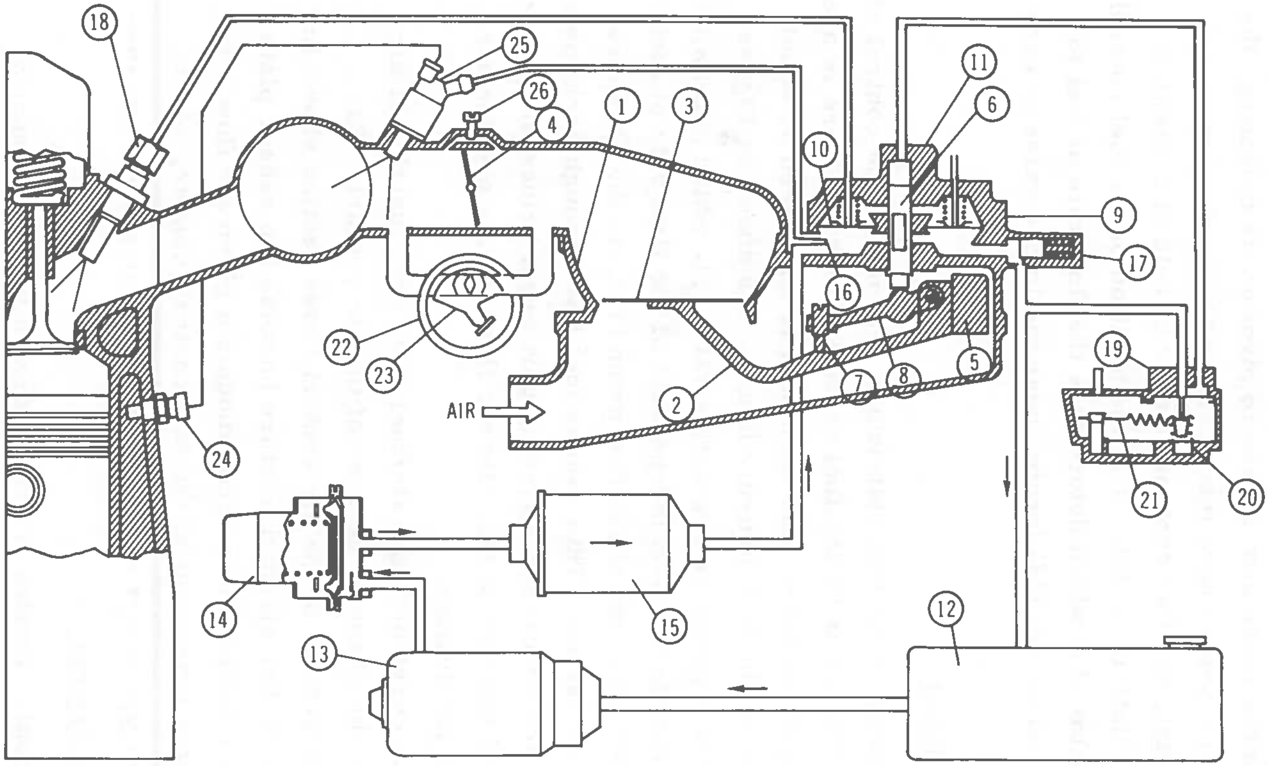
A conventional inlet air system is used with the 97-CID engine. Thermostatic control of inlet air is not used since fuel condensation in the intake manifold is not a problem with fuel injection, as it can be with carbureted systems.

5.1.3.3 Fuel System

The Audi 97-CID engine is equipped with the Bosch K Jetronic fuel injection system. In the K Jetronic system, fuel flow is continuous and proportional to the air flow in the intake system. For implementation of fuel flow rate control as a function of air flow rate, a mechanical air flow rate sensor forms the heart of the K Jetronic system. This unit, along with various ancillary devices, meters fuel in a manner that maintains the precise air/fuel ratio control required for optimum engine operation over a wide range of engine speeds and loads consistent with prevailing emission regulations. A description of the overall system is presented in the following material.

5.1.3.3.1 Air Flow Sensor

Figure 5-1 presents a diagram of the K Jetronic system. The air flow sensor is shown in its closed or rest position and consists of an air venturi (1), a pivoted lever arm (2), an air flow sensor plate (3), and a counterweight (5). Operation of the system depends on the position of the throttle (4), which is controlled by the vehicle operator. As the throttle is opened, air flow in the air venturi lifts the air flow sensor plate to a position which results in a



1	AIR VENTURI
2	LEVER
3	AIR FLOW SENSOR PLATE
4	THROTTLE PLATE
5	COUNTER WEIGHT
6	CONTROL PLUNGER
7	ADJUSTMENT SCREW
8	INTERMEDIATE LEVER
9	PRESSURE REGULATING VALVE
10	DIAPHRAGM
11	FUEL DISTRIBUTOR
12	FUEL TANK
13	FUEL PUMP
14	ACCUMULATOR
15	FILTER
16	METERING CHANNEL
17	PRESSURE REGULATOR
18	INJECTION VALVE
19	WARMUP REGULATOR
20	SPRING
21	BIMETALLIC STRIP
22	AUXILIARY AIR VALVE
23	PERFORATED PLATE
24	THERMO-TIME SWITCH
25	SOLENOID START VALVE
26	IDLE SPEED CORRECTION SCREW

FIGURE 5-1. CONTINUOUS FUEL INJECTION SYSTEM: AUDI 97-CID ENGINE

balance of opposing forces on each end of the lever arm. Offsetting the force resulting from air flow acting on the plate is a hydraulic force from the fuel control plunger (6). Since the lever arm is free to pivot on its mounting, the sensor plate is deflected to a point where intake air and hydraulic forces are in equilibrium. At this point, the fuel control plunger is held at a position determined by the intermediate lever (8). It is the position of the fuel control plunger in the fuel distributor (11) which determines the flow rate of fuel to each of the four individual injectors (18) located near the intake valve of each engine cylinder.

5.1.3.3.2 Fuel Distributor

The functioning of the fuel distributor depends on the control of rectangular slots or metering ports by the fuel control plunger. There is one metering port for each engine cylinder, and each port is uncovered an equal amount for a given position of the fuel control plunger. As shown in Figure 5-1, each metering port has a pressure regulating valve (9), which maintains a constant pressure drop across the port independent of the flow rate of fuel through the port, the supply pressure of the fuel pump (13), or the backpressure of the cylinder injector valves. This causes fuel flow through each metering port to depend only on the uncovered metering port area. Since the plunger position is a predetermined function of the inlet air flow rate, a precise air/fuel ratio is maintained by the system.

A particular curve defining air/fuel ratio as a function of air flow rate is determined by the shape or contour of the air venturi. For example, a less rapid enlargement of the air venturi cross section shown in Figure 5-1 would lead to a richer air/fuel mixture because the sensor plate would be subject to a larger deflection to accommodate a given air flow rate. This would result in a larger movement of the fuel control plunger, which gives an attendant increase in the rate of fuel flow for the given air flow rate.

5.1.3.3.3 Fuel Supply System

Two fuel supply circuits are incorporated in the fuel supply system. As shown in Figure 5-1, in the primary pressure circuit, fuel is drawn by the fuel pump (13) from the fuel tank (12) and is fed through an accumulator (14) and a filter (15) to the fuel distributor (11). The accumulator is included to damp pump noise and store pressure to ensure good hot start performance. In the fuel distributor, fuel passes through a channel which joins the lower chamber of each of the four metering port pressure regulating valves (9), mentioned previously. As a result, the same fuel pressure is applied to each metering port pressure regulator. The pressure is further regulated by the primary circuit pressure regulator (17). This regulator is a plunger type of unit and returns excess fuel to the tank. In addition, when the engine is shut off the regulator lowers the pressure to a "hold" level and then maintains this pressure until the engine is restarted.

The second fuel supply circuit, depicted in Figure 5-1, is the control pressure circuit. The control circuit is connected to the primary circuit through a bore in the fuel distributor and controls fuel flow via the warm-up regulator (19), which is a part of the control circuit. At low coolant temperatures, it reduces the pressure acting on the fuel control plunger and thus, for a given inlet air flow rate, allows the control plunger to uncover a larger metering port area during cold engine operation. This, in turn, provides a richer mixture to the engine to improve driveability during warmup. A spring (20) and bimetallic strip (21) implement warmup fuel pressure regulation. The bimetal strip is heated electrically after the engine is started. This causes the bimetal strip to lose tension and allows the spring to bring control pressure up to the normal operating level. As a result, enrichment gradually decreases until a normal operational air/fuel ratio is attained.

5.1.3.3.4 Starting System

The starting system, shown in Figure 5-1, consists of the solenoid start valve (25), which is actuated at the start of engine cranking, and a thermo-time switch (24). The start valve is controlled by the thermo-time switch, which limits the opening time of the valve, depending on engine temperature, and closes it completely above a certain temperature. When starting the engine in a cold condition, the auxillary air valve (22) is open and provides additional air to the engine for a high-speed idle. The additional air is measured by the air flow sensor, and therefore the engine is provided with the requisite amount of additional fuel to maintain the high-speed idle. The flow through the air valve is controlled by a perforated plate connected to a bimetallic strip which is electrically heated after startup. This causes the auxillary air supply to gradually diminish until a normal idle is attained.

On vehicles with a manual transmission, a manifold vacuum limiter is used. This device comes into operation during high-speed closed throttle deceleration and allows air to bypass the closed throttle when manifold vacuum exceeds 400-mm Hg. The vacuum limiter is used to limit creation of the unburned HC associated with the rich mixture generated during deceleration from high speeds.

5.1.3.3.5 Fuel Injection System Calibration

The air/fuel ratio calibration used with the 97-CID engine is presented in Table 5-3. Calibration data are given at four selected operating points ranging from idle to wide open throttle (WOT) and represent nominal values of air/fuel ratios. The tolerance associated with each of the four air/fuel ratios is ±5 percent.

As shown in Table 5-3, calibrations are unchanged between 1975 and 1976, as well as between California and 49-state vehicles. Except at WOT, the air/fuel ratios are set slightly above stoichiometric in order to provide excess air as an aid in post-combustion oxidation of HC and carbon monoxide (CO). As indicated in the table, this process is enhanced by an oxidizing catalytic converter on California vehicles.

5.1.3.4 Ignition System

5.1.3.4.1 Design Features

Audi uses a conventional breaker-point ignition system on the 97-CID engine. In addition to centrifugal spark advance, both vacuum advance and vacuum retard are employed. Vacuum retard is set at approximately 9 crank deg and is actuated by manifold vacuum. Ported vacuum obtained from a tap slightly downstream of the closed position of the throttle is used to actuate vacuum advance. Thus, during closed throttle idle or very light load, no vacuum is provided to the advance unit, and vacuum retard dominates. As the throttle opens, the vacuum advance port is uncovered, and vacuum retard is entirely eliminated.

On cars with air conditioning (A/C), spark retard is completely defeated when the A/C is turned on. This allows the engine to regain idle speed lost as a result of the A/C compressor load and decreases formation of

TABLE 5-3. CERTIFICATION CALIBRATION DATA: AUDI 97-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard										
	1976 49 States			1976 California		1975 49 States				1975 California	
Vehicle Model	F[a]	F[b]	F[a, c]	F[a]	F[b]	F[d]	F[d]	F[d]	F[d]	F[d]	F[d]
Transmission Type	A3	M4	M4	A3	M4	A3	M4	A3	M4	A3	M4
Vehicle Inertia Weight, lb	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Rear Axle Ratio	3.91	4.11	4.11	3.91	4.11	3.91	4.11	3.91	4.11	3.91	4.11
Catalyst	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes
Carburetor Calibration, A/F											
Idle: 0.82 lb/min air flow	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Off Idle: 2.0 lb/min air flow	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Part Throttle: 3.2 lb/min air flow	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
WOT at Max.: 11.9 lb/min air flow	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Basic Timing, crankshaft deg ATC	3	3	3	3	3	3	3	3	3	3	3
Centrifugal Advance, crankshaft deg											
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3000 rpm	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
4000 rpm	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
5000 rpm	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Vacuum Advance, crankshaft deg											
200 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
220 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
240 mm Hg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
260 mm Hg	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
280 mm Hg	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
300 mm Hg	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
320 mm Hg	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
EGR Valve Calibration											
Signal Pressure To Open, in. Hg	130	130	-	130	130	130	130	130	130	130	130
Flow at 300-mm Hg, liters/sec	5.3	5.3	-	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Fuel Economy, mpg											
City	25	24	-	23	24	19	22	23	21	21	22
Highway	33	37	-	32	36	31	37	34	34	33	34
Exhaust Emissions, g/m											
HC	1.3	1.0	0.9	0.3	0.2	0.7	1.3	1.3	1.1	0.3	0.2
CO	4.0	5.0	6.0	3.4	2.0	5.0	5.0	6.0	5.0	4.1	1.7
NO_x	1.9	2.2	2.3	1.5	1.2	1.0	1.9	1.7	1.3	1.2	0.9

[a] Audi Fox sedan

[b] Audi Fox wagon

[c] EGR is not used

[d] Audi Fox

HC and CO. California vehicles are equipped with a vacuum advance defeat for cold engine operation. Below 136°F, this device vents the vacuum advance signal to the atmosphere in order to decrease the engine warmup interval. Faster warmup lessens HC and CO formation because the catalyst is brought up to operating temperature more quickly.

5.1.3.4.2 Spark Advance Schedule

Table 5-3 presents spark advance schedules for the 1975 and 1976 model years. As shown in the table, basic timing as well as centrifugal and vacuum advance are unchanged over the two years. It should be noted that basic timing is 3 deg after-top-center (ATC) and, coupled with vacuum retard, provides ignition to the intake charge approximately 12 deg ATC at idle. This "late" timing promotes post-combustion oxidation of HC and CO and allows leaner idle mixtures for a given idle speed. Also, to assist in NO_x control, Audi uses lower overall spark advance settings than commonly used by other manufacturers.

5.1.3.5 Exhaust Gas Recirculation

5.1.3.5.1 Design Features

The exhaust gas recirculation (EGR) system used with the 97-CID engine uses a vacuum signal obtained from a venturi placed in the throttle housing well upstream of the throttle valve. Since the signal is derived at a point remote from the throttle, this EGR system is not of the ported type used by most manufacturers. At the throttle housing pick-off point, the EGR vacuum signal is too weak to actuate the EGR valve, and therefore a vacuum amplifier is used in conjunction with a high vacuum supply source. On 49-state vehicles, the amplifier relies on intake manifold vacuum and a small vacuum accumulator built into the amplifier assembly. California vehicles use an additional external vacuum accumulator which aids the maintenance of a high-vacuum source to actuate the EGR valve even during prolonged periods of low manifold vacuum. This causes California vehicles to provide more EGR than the 49-states vehicles under medium to heavy engine loads. A further difference between the 49-states and California vehicles is the use of an EGR filter on the 49-states vehicles. The filter is not used on California vehicles since they use unleaded gasoline to protect the catalyst and, as a consequence, do not have the lead fouling problem that the 49-states cars have. Both the 49-states and California vehicles incorporate a relief valve in the vacuum amplifier which effectively shuts off EGR during WOT conditions. In addition, a coolant temperature-actuated device which defeats EGR for coolant temperatures below 136°F is incorporated on both the 49-states and California vehicles.

5.1.3.5.2 EGR Calibration

Table 5-3 presents EGR valve calibration data. As shown in the table, both the 49-states and California vehicles use the same calibrations, and flow rate differences depend on the previously mentioned addition of an auxillary vacuum accumulator on California vehicles.

5.1.3.6 Secondary Air Injection

As indicated in Tables 5-1 and 5-3 some 1975 model 49-states vehicles use a secondary air injection system. The system is a conventional one consisting of an engine-driven air pump, a relief valve, and a check valve and is used to assist in the control of HC and CO.

5.1.3.7 Catalytic Converter

An oxidizing catalytic converter is used on California vehicles, as indicated in Table 5-1 and 5-3. The system is of an axial flow monolithic design and is used in conjunction with a relatively lean fuel injection calibration to provide excess oxygen to aid the catalyst in oxidizing HC and CO. Active materials are 90 percent platinum and 10 percent rhodium and offer an effective surface area of approximately 33 square meters.

5.1.3.8 Crankcase and Evaporative Emission Control

Conventional crankcase and evaporative emission control systems similar to those described in Section 3 are used on the 97-CID engine. The crankcase system is a closed one, and the evaporative system uses a sealed tank and a canister with activated carbon to retain fuel vapors.

5.1.3.9 Fuel Economy and Emissions

Table 5-3 lists the fuel economy and emissions data for the 1975 and 1976 California and 49-states Audi Fox certification vehicles (Refs.

5-8 through 5-11). These data are further presented by transmission type in Figures 5-2 and 5-3, which also show data for the Audi 100 to be discussed later. (The acronymns used in Figures 5-2 and 5-3 are identified in the "List of Abbreviations and Symbols".)

As shown in the subject figures, vehicles with either a manual or an automatic transmission exhibit an increase in fuel economy between 1975 and 1976. As Table 5-3 shows no year-to-year engine calibration changes which could affect fuel economy, the change is attributed to normal vehicle-to-vehicle and test-to-test variations. This conclusion is in concurrence with the rationale offered by Audi (Ref. 5-12).

It is interesting to note the difference in HC emissions between 1975 vehicles equipped with secondary air injection systems and both 1975 and 1976 vehicles without secondary air. As seen in Table 5-3, 1975 vehicles without a secondary air system average 20 percent higher HC emissions than 1975 models with air. In 1976, vehicles without air systems have slightly higher HC emissions than the 1975 vehicles with air injection. This data, along with similar information presented in Section 5.1.4.9 regarding the Audi 114-CID engine, is useful in making a rough assessment of the HC emission control capability attained by using secondary air injection on engines in the 100-CID class.

5.1.4 Audi 114-CID Engine

5.1.4.1 Engine Modifications

As shown in Table 5-2, little change has been made in the basic 114-CID engine parameters over the model years listed. One change noted is a slight decrease in compression ratio from 8.5:1 in 1972 to 8.0:1 in 1975 and 1976. The decrease was in response to a general reduction in fuel octane number implemented over the past several years. Intake-exhaust valve overlap is unchanged since 1974 as Audi uses EGR and ignition retard as its NO_x control methods.

5.1.4.2 Intake System

The inlet air control system on fuel injected models of the subject engine is not temperature-controlled. However, 1974 carburetor-equipped versions of the 114-CID engine use a conventional thermostatically controlled inlet air preheater.

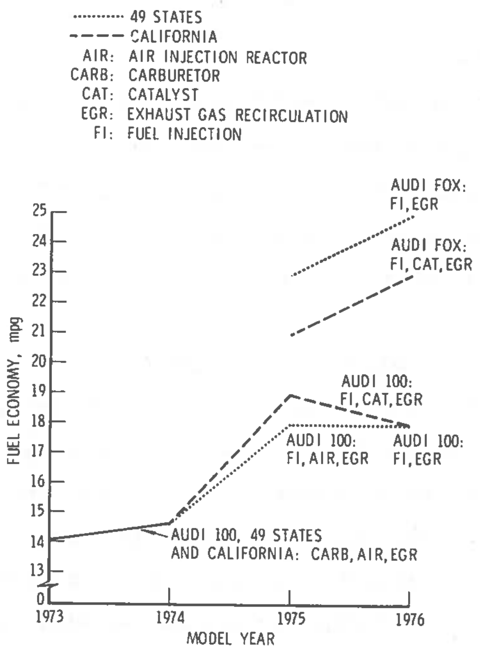


FIGURE 5-2. NORMALIZED AVERAGE CITY FUEL ECONOMY: AUDI FOX 97-CID AND AUDI 100 114-CID ENGINES WITH AUTOMATIC TRANSMISSION

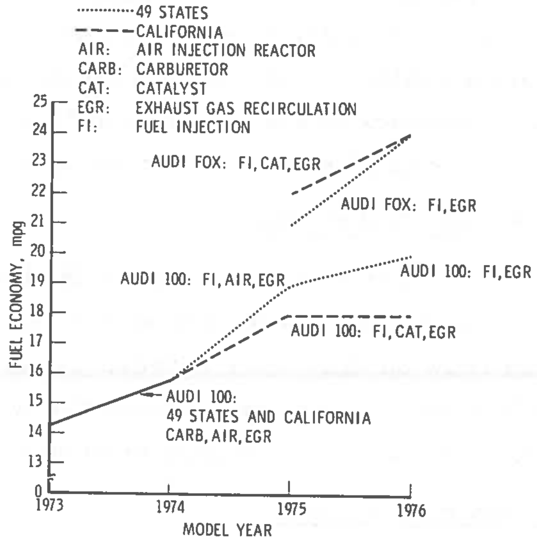


FIGURE 5-3. NORMALIZED AVERAGE CITY FUEL ECONOMY: AUDI FOX 97-CID AND AUDI 100 114-CID ENGINES WITH MANUAL TRANSMISSION

5.1.4.3 Fuel System

The 1975 and 1976 model year 114-CID Audi engine is equipped with the same fuel injection system used with the 97-CID engine. This system is described in Section 5.1.3.3. Details of the 1974 model year carburetor-based fuel system are presented in Table 5-2, and nominal air/fuel ratio calibrations for both the fuel injection and the carburetor are shown in Table 5-4.

As shown in Table 5-4, the 1972 and 1974 carburetor-based fuel systems are set richer at idle and leaner at off-idle, part-throttle and WOT than the fuel injected systems. Also, the excursions of the nominal air/fuel ratio between idle and part-throttle are wider in the carburetor-based systems. Air/fuel ratio tolerances are ±5 percent over the operating range for the fuel injection systems and vary from ±3.5 percent at idle to ±6 percent at off-idle and part-throttle for the carburetor fuel systems.

5.1.4.4 Ignition System

With one exception, the same general design features described in Section 5.1.3.4 for the 97-CID engine ignition system also apply to the 114-CID engine. The exception is the use of a capacitive discharge ignition system which is used on the 49-states vehicles equipped with an automatic transmission and on all California vehicles. The capacitive discharge system was introduced in 1973 and continues in use through the 1976 model year. Table 5-2 and 5-4 present further details and calibration data.

5.1.4.5 Exhaust Gas Recirculation

The same type of EGR system described in Section 5.1.3.5 for the 97-CID engine is used on the 114-CID engine. EGR calibration data are given in Table 5-4 and show no difference between California and the 49-states vehicles. Again, differences in flow rate between the two vehicle types depend on the additional vacuum accumulator used on California vehicles.

5.1.4.6 Secondary Air Injection

As indicated in Tables 5-2 and 5-4, secondary air injection is used on some models of the subject engine in 1974 and 1975. The system is a conventional one used to oxidize HC and CO and, as with the smaller 97-CID engine is discontinued in 1976.

TABLE 5-4. CERTIFICATION CALIBRATION DATA: AUDI 114-CID ENGINE

Engine / Vehicle Parameter	Model Year and Certification Standard															
	1976 49 States		1976 California		1975 49 States				1975 California		1974 49 States and California				1972
Vehicle Model	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Transmission Type	A3	M4	A3	M4	A3	M4	A3	M4	A3	M4	A3	M4	A3	M4	A3/M4
Vehicle Inertia Weight, lb	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	-
Rear Axle Ratio	3.91	4.11	3.91	4.11	3.91	4.11	3.91	4.11	3.91	4.11	3.91	3.91	4.11	4.11	-
Catalyst	No	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No
No. of Carburetor Venturis											2	2	2	2	
Carburetor Calibration, A / F															
Idle: 1.0 lb / min air flow	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	13.8	13.8	13.8	13.8	13.9
Off Idle: 2.0 lb / min air flow	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	15.4	15.4	15.4	15.4	16.5
Part Throttle: 4.1 lb / min air flow	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.9	15.9	15.9	15.9	15.9
WOT at Max.: 13.2 lb / min air flow	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	15.7[a]	15.7[a]	15.7[a]	15.7[a]	15.3[a]
Basic Timing, crankshaft deg ATC	6	6	6	6	6	6	6	6	6	6	6	6	6	6	8
Centrifugal Advance, crankshaft deg															
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3000 rpm	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0
4000 rpm	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
5000 rpm	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0
Vacuum Advance, crankshaft deg															
80 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100 mm Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
120 mm Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
140 mm Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
150 mm Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
EGR Valve Calibration															
Signal Pressure To Open, mm Hg	100	120	100	120	100	120	100	120	100	120	100	100	120	120	-
Flow at 300-mm Hg, liters / sec	10.0	5.3	10.0	5.3	10.0	5.3	10.0	5.3	10.0	5.3	10.0	10.0	5.3	5.3	-
Fuel Economy, mpg															
City	18	20	18	18	18	19	-	-	19	18	14.8[b]	14.5[b]	16.1[b]	15.4[b]	-
Highway	24	30	24	26	26	30	-	-	26	29	-	-	-	-	
Exhaust Emissions, g / m															
HC	1.4	1.2	0.3	0.3	0.9	1.1	1.2	1.1	0.4	0.3	-	-	-	-	-
CO	7.0	7.0	2.3	2.7	7.0	4.0	5.0	6.0	2.1	3.0	-	-	-	-	-
NO_x	2.7	1.8	1.4	1.7	2.1	1.9	2.0	1.6	1.6	1.2	-	-	-	-	-

[a] A / F at 9.6 lb / min air flow

[b] 1972 FTP

5.1.4.7 Catalytic Converter

As indicated in Tables 5-2 and 5-4, California vehicles use a catalytic converter in 1975 and 1976. The system is the same as the one described in Section 5.1.3.7 for use with the 97-CID engine.

5.1.4.8 Crankcase and Evaporative Emission Control

The 114-CID engine uses conventional crankcase and evaporative control systems similar to those described in Section 3. As with the 97-CID engine, the crankcase system is closed, and a carbon canister with a sealed gas tank is used in the evaporative control system.

5.1.4.9 Fuel Economy and Emissions

Fuel economy and emission data for the 49-states and California Audi-100 certification vehicles are given in Table 5-4 (Refs. 5-8 through 5-13). These data are also presented as plots in Figures 5-2 and 5-3, which show data for automatic and manual transmission vehicles, respectively.

As shown Figures 5-2 and 5-3, a substantial increase in fuel economy is shown between the 1974 and 1975 model years. This increase occurs with the change from a carburetor to a fuel injection based fuel delivery system. As fuel injection generally provides a more efficient use of fuel than a carburetor and since no other calibration changes have been made between 1974 and 1975, the increased economy is attributed to the introduction of fuel injection. Changes in fuel economy between 1975 and 1976 are relatively small, and since no calibration changes occur between these two model years the fluctuations are attributed to normal test-to-test and vehicle-to-vehicle variations.

Relative to 1975, 49-states vehicles with secondary air injection corresponding to 1975 and 1976 vehicles without secondary air show respective 15 and 30 percent higher HC emissions. This provides an indication of the effectiveness of secondary air injection on HC control in fuel injected vehicles.

5.2 BAVARIAN MOTOR WORKS A.G.

5.2.1 Engine/Vehicle Configurations

The Bavarian Motor Works A.G. (BMW) 4-cylinder water-cooled 121.8-CID engine has been selected for review in this study. This engine is used in the carbureted 2002 vehicles and in the fuel injected 2002 tii vehicles. The carbureted version has been marketed in the United States since 1966, whereas the fuel injected model was available in the United States only between 1972 and 1974.

Prior to model year 1976, there was no distinction between the California and 49-states vehicles. However, different emission control systems are employed in the two vehicle categories in 1976. As shown in Table 5-5, the thermal reactor and EGR systems used in all 1975 model year vehicles have been eliminated from the 49-states vehicles in 1976 (Refs. 5-14 through 5-19).

5.2.2 Engine Design Features

Important specification data for the BMW 121.8-CID engine are presented in Table 5-5. While the basic design of the engine has remained unchanged since 1968, a number of component modifications have been incorporated over the years including a step-wise reduction in the compression ratio, a reduction in surface-to-volume ratio in 1975, and the previously noted optional use of fuel injection in 1974. In addition, the valve timing is modified in 1970 and again in the 1976 model 49-states vehicles, and a number of emission control devices and techniques have been added in recent years to meet the prevailing emission regulations. The small change in combustion chamber surface-to-volume ratio in 1975 is partly attributed to the reduction in compression ratio and partly to design modifications of the intake port. As shown in Table 5-5, opening of the intake valve is advanced in 1970 and combined with late closing of the exhaust. As a result, the exhaust system remains in communication with the engine intake for a longer period of time. This increases the backflow of exhaust gases into the low pressure intake system and causes a reduction in the HC and NO_x emissions.

5.2.3 Intake System

The 1966-1970 model year engines are equipped with a conventional unheated intake manifold system. Conversely, a tuned intake manifold is used in all 1974 and later model year engines, resulting in lower pumping losses and improved fuel/air mixture distribution. In addition, intake air preheating has been used since 1974 to enhance the fuel vaporization process and to improve the cold start characteristics of the engine. The air heating system which is similar to previously discussed arrangements consists of an exhaust manifold stove and a thermostatically controlled mixing valve. This valve is designed to maintain a constant air cleaner temperature of about 70°F. For ambient temperatures above 70°F, the valve is fully closed shutting off the supply of heated air.

5.2.4 Fuel System

5.2.4.1 Carburetor Design Features

As indicated in Table 5-5, a Solex single-venturi downdraft carburetor is used in 1970 and prior model years. This unit is of conventional design and includes an idle circuit, a main fuel circuit, an accelerator pump, a power enrichment system, and a manual choke. In 1970 a dashpot was added to reduce the HC and CO emissions during vehicle deceleration and at idle. This device consists of a speed-sensitive solenoid valve and an electronic control unit which maintains a carburetor throttle opening of about 3-4 deg by means of a throttle closure delay diaphragm until the engine speed has declined to the fast idle "trip point" of approximately 1800 rpm. For engine speeds above 1800 rpm, the solenoid valve is energized, connecting the dashpot with atmosphere and preventing throttle closure. Conversely, at speeds below 1800 rpm, the solenoid valve is de-energized, and the dashpot is connected to intake manifold vacuum, allowing the throttle to gradually return to its normal idle position.

The 1974-1976 carburetors are equipped with an automatic choke which is controlled by means of a bimetallic spring. The choke housing is heated by engine coolant and by an electric assist heater. Two temperature sensors are used for on-off control of the electric heater. One sensor is located near the cylinder head, whereas the other is inserted into the cooling jacket. Electric choke heating is provided either when the first sensor reaches a temperature of 63°F or when the coolant temperature is above about 115°F. The objective of the second sensor is to accelerate choke opening in the case of a warm engine, hence preventing operation of the engine with excessively rich mixtures.

In addition, the 1974 and later model year carburetors employ a thermostatically controlled and electrically heated thermo-starter valve.

TABLE 5-5. ENGINE SPECIFICATIONS: BMW 121.8-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1970		1968	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4		4	
Bore, in.	3.50		3.50		3.50		3.50		3.50	
Stroke, in.	3.15		3.15		3.15		3.15		3.15	
Displacement, cu in.	121.8		121.8		121.8		121.8		121.8	
Surface/Volume, 1/in.	5.98		5.98		6.43		-		-	
Compression Ratio	8.1		8.1		8.3 or 9.0[a]		8.5		8.5	
Cylinder Head Type	-		-		-		-		-	
Advertised HP at Engine Speed, rpm	96 at 5500		96 at 5500		98 or 125[a] at 5500		113[b] at 5800		113[b] at 5800	
Torque, ft-lb, at Engine Speed, rpm	106 at 3500		106 at 3500		106 or 127[a] at 3500 or 4000[a]		116[b] at 3000		116[b] at 3000	
Exhaust System Type	Single		Single		Single		Single		Single	
Combustion Chamber Configuration	Hemisphere		Hemisphere		Hemisphere		Hemisphere		Hemisphere	
Intake Valve Diameter, in.	1.81		1.81		1.81		-		-	
Intake Valve Lift, in.	0.36		0.361		0.32		-		-	
Exhaust Valve Diameter, in.	1.50		1.50		1.50		-		-	
Exhaust Valve Lift, in.	0.361		0.361		0.32		-		-	
Intake Valve Opens, deg BTC	24	18	18		18		18		4	
Intake Valve Closes, deg ABC	68	66	66		66		66		52	
Intake Valve Duration, deg	272	264	264		264		264		236	
Exhaust Valve Opens, deg BBC	72	66	66		66		66		52	
Exhaust Valve Closes, deg ATC	12	18	18		18		18		4	
Exhaust Valve Duration, deg	264	264	264		264		264		236	
Valve Overlap, deg	36	36	36		36		36		8	
Distributor Type	Breaker point		Breaker point		Breaker point		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC	-3		-3		-5		0		3	
Idle Speed, rpm	900		900		1000 925[a]		1000		1000	
Fast Idle Speed, rpm	1800		1650		1800		1800		-	
Fuel System Type	2-V downdraft DVG		2-V downdraft DVG		2-V downdraft or FI		1-V downdraft Solex		1-V downdraft Solex	
Fuel Metering Method										
Enrichment Method	2-stage power valve		2-stage power valve		2-stage power valve		-		-	
Choke Type	Automatic		Automatic		Automatic		Manual		Manual	
Carburetor Venturi Diameter, in.	0.945 (1V) 1.031 (2V)		0.945 (1V) 1.031 (2V)		0.945 (1V) 1.031 (2V)		-		-	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	118.5 at 0.75		118.5 at 0.75		118.5 at 0.75		-		-	
Emission Control Systems	AIR EVAP PCV	AIR EGR EVAP PCV TR[e]	AIR EGR EVAP PCV TR[e]		EGR[c] EVAP PCV		AIR EVAP PCV		AIR PCV	
Emission Control Devices		Spark retard	Spark retard		Spark retard deceleration fuel[d]		-		-	

[a] With fuel injection

[b] Gross rating

[c] Only with carburetor

[d] Only with fuel injection

[e] TR = thermal reactor

The function of this device is to enrich the mixture during an engine cold start, independent of the position of the automatic choke. This improves vehicle driveability and accelerates engine warmup. Heating of the bimetallic spring of the valve commences when the ignition switch is in the "on" position. The system is deactivated when the temperature of the bimetallic spring exceeds $59^{\circ}F$.

To prevent excessive heating of fuel in the carburetor float bowl and to eliminate vapor lock in the fuel supply line, a return valve is provided between the carburetor and the fuel tank, which reroutes any excess fuel back into the fuel tank. This arrangement provides for better idle mixture control.

The DVG carburetor used in 1975 and 1976 incorporates a two-stage fuel metering system with fixed orifices. At high loads, fuel enrichment is provided by a two-stage power valve. All other carburetor functions are identical to the 1974 unit, except that the control temperature of the second choke sensor is increased to about $150^{\circ}F$.

5.2.4.2 Carburetor Calibration

Typical carburetor calibration data, exemplified by the 1976 model configuration, are presented in Figure 5-4, showing air/fuel ratio versus carburetor flow rate. The calibration is conventional, increasing rapidly in the low flow regime, followed by a gradual decline at high flow rates.

Calibration data for other model years are presented in Table 5-6. As indicated, the air/fuel ratio settings remained nearly constant between 1974 and 1976, except for a moderate increase at WOT in 1975 and 1976. Conversely, richer mixtures were employed in 1968.

The calibration tolerance band in 1976 is about ±5 percent which is higher than the ±3 - ±4 percent permitted in earlier model years.

5.2.4.3 Fuel Injection System Design Features

The fuel injection system used by BMW is shown schematically in Figure 5-5. The four-plunger mini-pump (7) delivers fuel to four injectors located in the intake manifold near the intake valves. The injection nozzles are set to open at 430-540 psi. In addition, fuel is provided by a gear-type fuel pump (3) directly to a starting valve (11), placed just upstream of the

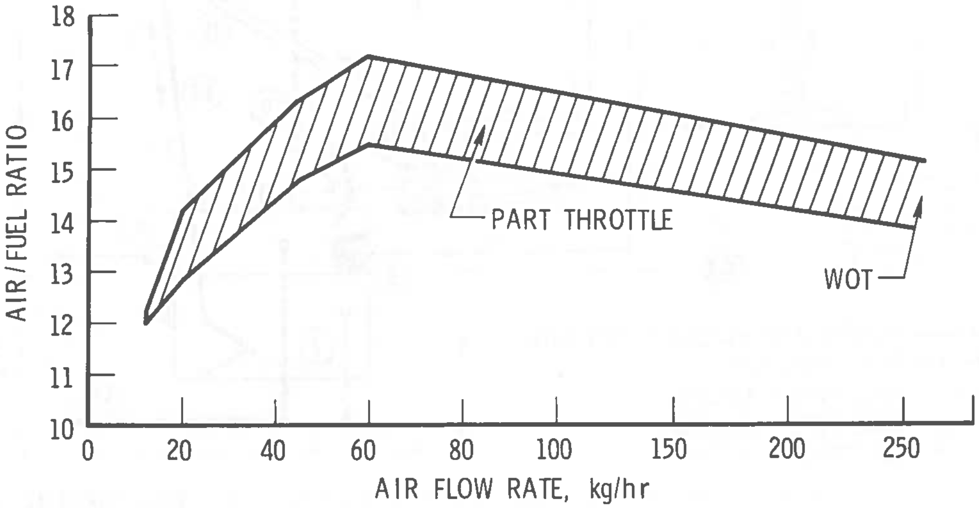
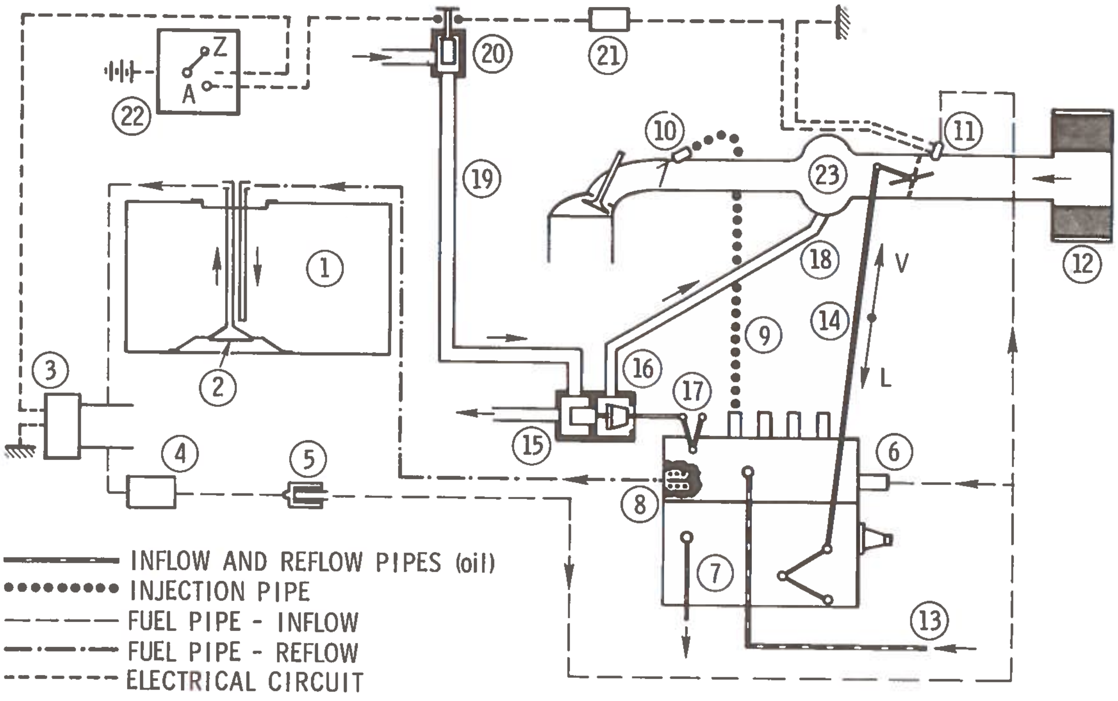


FIGURE 5-4. CARBURETOR CALIBRATION: 1976 BMW 121.8-CID ENGINE; 49-STATES CALIBRATION

throttle plate. The opening time of the starting valve is controlled by a time switch (21) and a coolant temperature operated switch (20). The quantity of fuel injected into the engine is determined by a three-dimensional cam which is moved longitudinally by means of a linkage arrangement to the accelerator pedal. The angular position of the cam is controlled by an engine speed sensor.

During engine warmup, additional fuel is provided by an automatic choke unit, which is activated until the engine coolant temperature reaches about 145°F. This device consists of a heat-sensitive expansion element (15) which, by means of an eccentric shaft, decreases the amount of injected fuel as the coolant temperature increases. Simultaneously, the air supply is reduced by means of an air flow adjustment cone (16).



1. Fuel tank with induction unit
2. Fine-mesh filter in induction unit
3. Fuel pump
4. Expansion container for pressure balance
5. Main fuel filter
6. Fine-mesh filter in fuel intake
7. Injection pump
8. Fuel reflow with pressure valve
9. Injection pipe
10. Injection valve
11. Starter valve
12. Air filter
13. Inflow and reflow of engine oil
14. Adjustment engine idling speed - full throttle (by accelerator pedal)
15. Warm-up unit with expansion element
16. Air adjustment cone
17. Lever for eccentric shaft
18. Intake pipe for additional air
19. Coolant pipe
20. Temperature time switch
21. Time switch
22. Ignition switch
23. Air container

FIGURE 5-5. FUEL INJECTION SYSTEM: 1974 BMW 121.8-CID ENGINE

For HC control during deceleration and idle, additional air is bled into the intake manifold through the limiter valve (16). This valve opens at high vacuum permitting additional air flow (18) from the air filter (12) into the intake manifold. This device, combined with the closely controlled injection pump delivery at idle, provides the desired air/fuel mixture.

Air/fuel calibration data are not available for the fuel injection system.

5.2.5 Ignition System

5.2.5.1 Design Features

All BMW 121.8-CID engines are equipped with a conventional ignition system. As indicated in Table 5-6, the 1968 and 1970 models employ both centrifugal and vacuum mechanisms. However, instead of vacuum advance, the carbureted 1974 model engine uses vacuum retard at normal idle as well as under fast idle conditions when the engine is cold. As a result, the HC emissions are reduced. Conversely, the fuel-injected 1974 engine is equipped with a dual diaphragm advance/retard system which provides normal advance, except at idle and during vehicle deceleration when spark retard is implemented. This particular system consists of a speed-controlled solenoid valve which is energized at engine speeds below 2500 rpm. In this case, one side of the diaphragm chamber is connected to ambient pressure, rendering vacuum advance inoperative. At higher speeds, the valve is deenergized, connecting the other side of the diaphragm chamber to port vacuum, and hence, activating the vacuum advance mechanism.

The 1975 vehicles with automatic transmission use a vacuum advance system. However, the carburetor vacuum port is positioned in such a manner that vacuum advance is provided only in the low-load regime. In addition, a coolant temperature-controlled solenoid valve is installed in the vacuum line to the distributor which interrupts port vacuum to the diaphragm chamber when the coolant temperature exceeds about 150°F. As a result, ambient pressure is admitted to the distributor, and vacuum advance is deactivated.

The manual transmission vehicles are equipped with an advance/retard mechanism which provides normal spark advance for all operating

TABLE 5-6. CERTIFICATION CALIBRATION DATA: BMW 121.8-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard											
	1976 49 States		1976 California		1975 49 States and California		1974 49 States & Calif Fuel-Injected		1974 49 States Carbureted		1970	1968
Transmission Type	A	M4	A	M4	A	M4	M4	M4	A	M4	-	-
Vehicle Inertia Weight, lb	2750	2750	2750	2750	2750	2750	2750	2750	2750	2750	-	-
Rear Axle Ratio	3.90	3.90	3.64	3.64	3.64	3.64	3.64	3.64	3.40	3.64	-	-
Carburetor Calibration, A/F												
Idle: 12-kg/hr air flow	12.0	12.0	12.0	12.0	12.0	12.0	-	-	12.0	12.0	-	10
Off Idle: 20-kg/hr air flow	13.5	13.5	13.8	13.8	13.8	13.8	-	-	13.8	13.8	-	11
Part Throttle: 65-kg/hr air flow	16.3	16.3	15.5	15.5	15.5	15.5	-	-	15.6	15.6	-	14.8
WOT: 260-kg/hr air flow	14.5	14.5	14.2	14.2	14.2	14.2	-	-	13.2	13.2	-	12.8
Basic Timing, crankshaft deg BTC	-3	-3	-3	-3	-3	-3	-5	-5	-5	-5	0	3
Centrifugal Advance, crankshaft deg												
1000 rpm	6	6	6	6	6	6	0	0	6	6	6	6
1500 rpm	16	16	16	16	16	16	14	14	18	18	18	18
2000 rpm	24	24	24	24	24	24	11	11	26	26	26	26
3000 rpm	34	34	34	34	34	34	28	28	30	30	30	30
4000 rpm	38	38	38	38	38	38	30	30	30	30	30	30
5000 rpm	38	38	38	38	38	38	30	30	30	30	30	30
Vacuum Advance, crankshaft deg												
5 in. Hg	0	0	0	0	0	0	0	0	-	-	0	0
6 in. Hg	2	2	2	2	2	2	0	0	-	-	2	2
8 in. Hg	6	6	6	6	6	6	0	0	-	-	8	8
10 in. Hg	12	12	12	12	12	12	0	0	-	-	10	10
≥12 in. Hg	14	14	14	14	14	14	0	0	-	-	10	10
Vacuum Retard, crankshaft deg												
8 in. Hg	0	0	0	2	0	2	2	2	-	-	0	0
10 in. Hg	0	0	0	6	0	6	6	6	-	-	0	0
12 in. Hg	0	0	0	10	0	10	10	10	-	-	0	0
≥15 in. Hg	0	0	0	12	0	12	12	12	-	-	0	0
EGR System	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Fuel Economy, mpg												
City	19	18	19	20	20	18	20.3[a]	18.1[a]	22.1[a]	21.1[a]	-	-
Highway	26	25	28	30	29	30	-	-	-	-	-	-
Exhaust Emissions, g/m												
HC	0.9	0.8	0.5	0.4	0.3	0.3	-	-	-	-	-	-
CO	10	10	7	5	7	3	-	-	-	-	-	-
NO_x	2.9	2.0	1.4	1.4	1.1	1.0	-	-	-	-	-	-

[a] 1972 FTP

conditions except idle and low-load operation. For engine temperatures above 150°F, the solenoid valve installed in the vacuum line is energized, admitting ambient pressure to the diaphragm chamber, thus activating the retard mechanism. As a result, ignition retard occurs only at idle and low engine loads after the engine is warmed up. The resulting reduction in engine torque requires additional throttle opening, leading to higher intake manifold pressure and better combustion.

The retard feature has been eliminated in the 1976 model 49-states vehicles. However, the operation of the vacuum advance unit is controlled by a coolant temperature sensor similar to the configuration used in the 1975 vehicles with automatic transmission. In this case, vacuum advance is implemented only for coolant temperatures below 113°F. The centrifugal and vacuum advance mechanisms used in the 1976 California vehicles with automatic and manual transmission are similar to the corresponding 1975 systems.

5.2.5.2 Spark Advance Schedules

The centrifugal and vacuum advance settings are listed in Table 5-6 at discrete engine speed and carburetor port vacuum settings. Also shown in the table is the basic timing, which varies from about 3 crankshaft deg before top center (BTC) in 1968 to 5 crankshaft deg ATC in 1974.

The sum of basic timing and centrifugal spark advance declines in 1970 relative to 1968, followed by an additional reduction in 1974, particularly for the fuel-injected vehicles at low engine speeds. For speeds of 2000 rpm and lower, the combined basic timing and centrifugal advance have remained constant between 1974 and 1976, while additional advance has been introduced in the high-speed regime in 1975 and 1976.

The vacuum advance has remained unchanged between 1968 and 1970, followed by elimination of the vacuum advance feature in the carbureted 1974 vehicles and a moderate increase in the advance in 1975 and 1976. However, as previously noted, the vacuum advance mechanism is deactivated in these vehicles for significant portions of the Federal Driving Cycle.

The calibration tolerances have remained near ±3 crankshaft deg over the past several years for both centrifugal and vacuum advance mechanisms.

5.2.6 Exhaust Gas Recirculation

5.2.6.1 Design Features

As indicated in Table 5-5, EGR is used in all 1975 vehicles as well as in some 1976 and 1974 vehicles. In order to prevent a loss in engine power, the system is rendered inoperative at full throttle.

The EGR system consists of a vacuum-controlled two-stage EGR valve which meters exhaust gases into the intake manifold. The valve has two diaphragm chambers, and the motion of the diaphragms controls the flow rate through the valve. The first stage is connected to a vacuum tap near the throttle closed position. When the vacuum reaches about 3.15-in. Hg., corresponding to an idle speed of 2500 rpm, the first-stage diaphragm lifts slightly, opening the EGR valve and allowing a small amount of exhaust gas into the intake manifold. The second stage of the EGR valve opens when the intake manifold vacuum exceeds a predetermined value. This requirement is met by the operation of a control valve which regulates the vacuum supply to the second stage of the EGR valve. At low vacuum levels, the diaphragm in the control valve is lifted, connecting the second stage with ambient air drawn through a filter. As intake manifold pressure increases, the diaphragm in the control valve is lowered until a small shuttle valve is closed, providing vacuum to the second diaphragm chamber. This causes further opening of the EGR valve (by 0.118 in.), resulting in higher exhaust gas flow. The maximum EGR flow corresponds to approximately 8-10 percent of the air flow through the engine.

Two additional EGR flow control circuits are used by BMW, which eliminate EGR with a cold engine, during idle, and near WOT. The cold temperature cutoff system consists of a three-way solenoid valve which is controlled by a coolant temperature sensor (T_1) and a second sensor (T_2), which is driven by cylinder head temperature. For sensor temperatures of 113°F (T_1) and 63°F (T_2), the solenoid is energized, and the control valve is then vented to atmosphere, hence preventing opening of the second stage of the EGR valve and maintaining acceptable vehicle driveability.

EGR cutoff at idle and near WOT is achieved by properly matching the spring constant and the location of the carburetor vacuum port.

A warning light is incorporated in all EGR-equipped 1975 and 1976 model engines. This light is turned on at 12,500 mile intervals, indicating the need for EGR system maintenance.

5.2.6.2 EGR Valve Calibration

EGR valve calibration data are presented in Figure 5-6, showing air flow rate through the valve as a function of signal vacuum. These data are applicable to all 1974 through 1976 engines incorporating EGR.

5.2.7 Secondary Air Injection and Thermal Reactor

All BMW 121.8-CID engines considered in Table 5-5, except model year 1974, are equipped with a conventional secondary air system, consisting of an engine driven vane type air pump, a diverter valve and an antibackfire valve. The air is injected into the exhaust manifold in the vicinity of the exhaust valve. The diverter valve is designed to prevent engine backfire during deceleration by cutting off air injection temporarily. This is achieved by connecting the diverter valve diaphragm chamber with intake manifold vacuum. During deceleration, the high intake manifold vacuum actuates the diverter valve diaphragm, which then closes the valve, rerouting the secondary air supply to atmosphere. A small orifice in the diaphragm chamber allows for pressure equalization on both sides of the diaphragm and restores air injection after about 3 seconds.

The pressure relief valve is built into the diverter valve to prevent excessive backpressure in the exhaust manifold and also to protect the thermal reactor against excessively high temperatures. The pressure relief valve starts to open at 5.0 psi, discharging the air to atmosphere.

The check valve protects both pump and valve from hot exhaust gas backflow in case of belt failure or pressure relief valve malfunction.

All 1975 engines and the engines used in the 1976 California vehicles are equipped with a thermal reactor for additional HC and CO control. The reactor, which is attached to the exhaust manifold, is fabricated from thin sheetmetal (Inconel 600) to allow for quick heating. It is externally insulated (0.4-inch thickness Fiberfrax H) and is provided with a metal shell for reinforcement and gas tightness. The thermal reactor shape is configured to promote mixing of secondary air and exhaust gas and to increase the residence time of the gases in the hot zone.

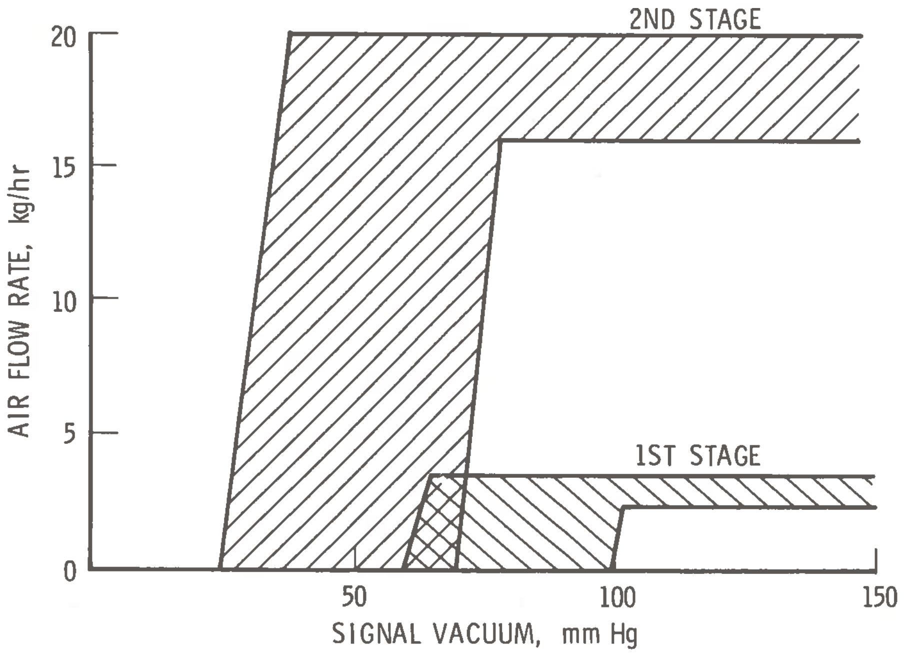


FIGURE 5-6. EGR VALVE CALIBRATION: BMW 121.8-CID ENGINE

The system is equipped with a warning light that requires maintenance at 25,000-mile intervals. The warning light switch is reset at the time of maintenance.

5.2.8 Catalytic Converter

Unlike most other manufacturers, BMW does not use catalysts in any of its engines, relying on the thermal reactor to carry the HC and CO emission control burden.

5.2.9 Crankcase and Evaporative Emission Control

All 1968-1976 model 121.8-CID engines are equipped with a sealed crankcase emission control system which is functionally identical to the unit described in Section 3, transferring the crankcase vapors to the downstream side of the air cleaner. Vacuum in the crankcase is controlled by means of a calibrated bypass line connecting the blowby gas pipe to the intake manifold. A small orifice (0.098-inch in diameter) and a labyrinth arrangement are provided in the bypass line to prevent the transfer of oil into the engine intake.

A conventional evaporative emission control system has been employed by BMW since 1970, consisting of a vapor separator and a vent line to the engine crankcase. After the engine is started, the fuel vapors collected in the crankcase are drawn into the air cleaner through the crankcase ventilation line. In 1975, a charcoal canister was added to assume the fuel vapor storage function of the crankcase.

5.2.10 Fuel Economy and Emissions

The available fuel economy and emission data for the BMW 1974-1976 model 121.8-CID engine equipped vehicles are listed in Table 5-6 (Refs. 5-8, 5-10, 5-11, and 5-13). Following the method outlined in Section 3, the fuel economy data have been normalized to a common vehicle inertia weight of 2750 pounds and rear axle ratio of 3.89, as shown in Figure 5-7. Also plotted in this figure is the average 1973 city cycle fuel economy of the carbureted vehicles, computed from Ref. 5-20 and upgraded by 5 percent to account for test procedure differences (Section 3).

The fuel economy gains observed in the carbureted 1974 vehicles relative to 1973 are rather small, varying between about 2 percent for the manual transmission to about 5 percent for the automatic transmission. Considering the nearly constant carburetor and spark advance settings used between 1974 and 1975, the 15 percent drop in fuel economy in 1975 for both manual and automatic transmission vehicles can not be rationalized, although the compression ratio is reduced slightly in 1975 and spark retard has been introduced in conjunction with the manual transmission. In 1976, the retard feature is eliminated, resulting in moderate fuel economy improvements for the manual transmission configurations.

Because of the elimination of EGR in the 1976 model 49-states vehicles, moderately higher fuel economy would have been expected for these vehicles relative to 1975. However, Figure 5-7 shows actually a small decline, which is attributed entirely to normal test-to-test and vehicle-to-vehicle variabilities since no other calibration changes are implemented in 1976.

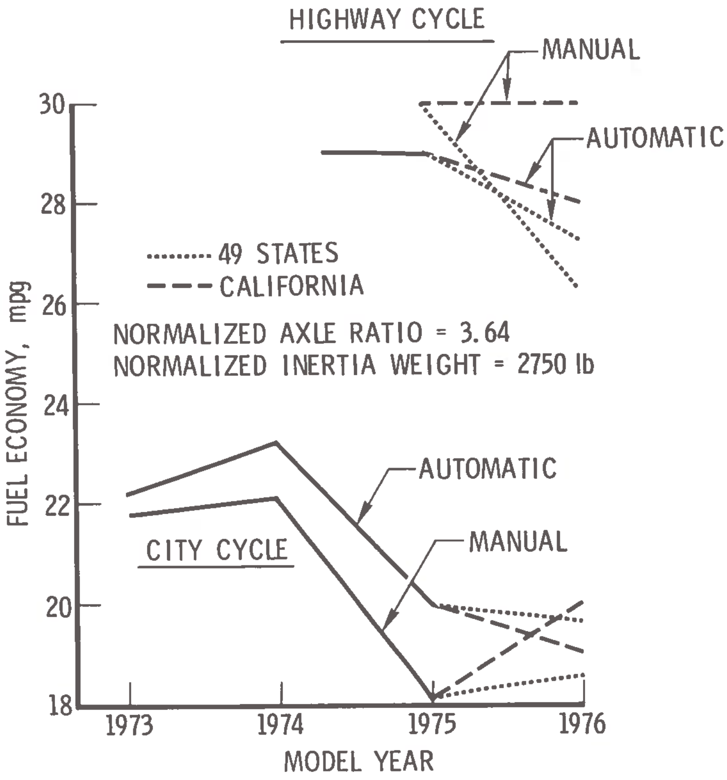


FIGURE 5-7. NORMALIZED AVERAGE FUEL ECONOMY: BMW 121.8-CID CARBURETED ENGINE

Following generally accepted trends, the city fuel economy of the 1973 vehicles with fuel injection is slightly higher than for the corresponding carbureted vehicles (Ref. 5-20). Conversely, Table 5-6 shows the opposite trend for 1974, which is partly caused by lower air/fuel mixture settings used in the 1974 fuel-injected engines (Ref. 5-19).

Except for the California vehicles with manual transmission, the highway fuel economy shows a declining trend between 1975 and 1976. Again, this is difficult to rationalize considering the nearly constant carburetor and distributor calibrations used for these two model years.

With regard to exhaust emissions, NO_x control is achieved primarily by means of EGR, combined with appropriate adjustments in mixture ratio and spark timing. The substantial reduction in HC and CO realized in 1975 relative to 1974 is achieved by the addition of secondary air injection in all 1975 and 1976 vehicles, combined with a thermal reactor in all 1975 vehicles and in the 1976 California vehicles. As a result of the elimination of EGR, the 1976 model 49-states vehicles show higher NO_x relative to 1975, but without the expected gain in fuel economy.

5.3 BRITISH LEYLAND

5.3.1 Engine/Vehicle Configurations

Two 4-cylinder, in-line, overhead valve engines with 91- and 110-CID have been chosen to represent engine control practices of British Leyland. The 91-CID unit is used in the MG Midget and the Triumph Spitfire, which are both currently rated at 2000-pounds inertia weight in the 49-states and 2250-pounds in the California vehicles. The 110-CID engine is used in the MGB and the Austin Marina. The latter two vehicles place models in the 2500-pound inertia weight class, and the MGB also has a 3000-pound model. The Austin Marina has been available through the 1975 model year but is not currently sold in the United States. Prior to 1976, it has been available with a three-speed automatic transmission as well as a four-speed manual transmission. All other 91-CID and 110-CID equipped vehicles use a four-speed manual transmission.

5.3.2 Engine Design Features

Tables 5-7 and 5-8 present an overview of the subject engine families (Refs. 5-21 through 5-28). An interesting 1976 addition to the 91-CID engine family is the high compression (9.1:1) engine shown in Table 5-7. This unit is only available in the 49 states. In California, the 91-CID engine compression ratio remains at 7.5:1. The 110-CID engine uses a more moderate 8.0:1 compression ratio and applies catalytic control to a greater extent than the 91-CID unit.

5.3.3 British Leyland 91-CID Engine

5.3.3.1 Engine Modifications

Aside from the previously mentioned increase in compression ratio, the 91-CID engine shows little year-to-year change in basic engine

TABLE 5-7. ENGINE SPECIFICATIONS: BRITISH LEYLAND 91-CID ENGINE

Engine Parameter	Model Year					
	1976		1975		1974	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4	
Bore, in.	2.9		2.9		2.9	
Stroke, in.	3.44		3.44		3.44	
Displacement, cu in.	91		91		91	
Surface/Volume, 1/in.	8.04	6.75	6.75		6.75	
Compression Ratio	9.1	7.5	7.5		7.5	
Cylinder Head Type	OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	52.5 at 5000, Spitfire[a] 48 at 5000, MG Midget[a]		52 at 5000, Spitfire		57 at 5000, Spitfire	
Torque, ft-lb, at Engine Speed, rpm	69 at 2500, Spitfire[a] 67 at 2500, MG Midget[a]		69 at 2500, Spitfire		74 at 3000, Spitfire	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Bathtub		Bathtub		Bathtub	
Intake Valve Diameter, in.	1.38		1.38		1.44	
Intake Valve Lift, in.	0.353		0.353		0.353	
Exhaust Valve Diameter, in.	1.17		1.17		1.17	
Exhaust Valve Lift, in.	0.349		0.349		0.349	
Intake Valve Opens, deg BTC	18		18		18	
Intake Valve Closes, deg ABC	58		58		58	
Intake Valve Duration, deg	256		256		256	
Exhaust Valve Opens, deg BBC	58		58		58	
Exhaust Valve Closes, deg ATC	18		18		18	
Exhaust Valve Duration, deg	256		256		256	
Valve Overlap, deg	36		36		36	
Distributor Type	Breakerless; centrifugal advance, vacuum retard		Breakerless; centrifugal advance, vacuum retard		Breaker point; centrifugal advance, vacuum retard	
Basic Ignition Advance, deg BTC, at Engine Speed, rpm	2 at 800		2 at 800		2 at 800	
Idle Speed, rpm	800		800		800	
Fast Idle Speed, rpm	-		-		-	
Intake Air Temperature Control	Thermostatic		Thermostatic		Thermostatic	
Fuel System Type	1V sidedraft carburetor		1V sidedraft carburetor		1V sidedraft carburetor	
Fuel Metering Method	Variable orifice, metering needle		Variable orifice, metering needle		Variable orifice, metering needle	
Enrichment Method	Oil damper on air valve		Oil damper on air valve		Oil damper on air valve	
Choke Type	Manual		Manual		Manual	
Carburetor Venturi Diameter, in.	1.5		1.5		1.5	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	100 at 1.25		100 at 1.25		100 at 1.25	
Emission Control Systems	AIR CAT[a] EGR EVAP PCV		AIR CAT[a] EGR EVAP PCV		EGR EM EVAP PCV	
Emission Control Devices	Antirunon valve EGR/choke COS EGR service indicator Heated intake air Throttle bypass valve		Antirunon valve EGR/choke COS EGR service indicator Heated intake air Throttle bypass valve		Antirunon valve Thermal ignition advance EGR/choke COS Heated intake air Throttle bypass valve Thermal ignition retard COS	

[a] California vehicles only

TABLE 5-8. ENGINE SPECIFICATIONS: BRITISH LEYLAND 110-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1970	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4	
Bore, in.	3.16		3.16		3.16		3.16	
Stroke, in.	3.50		3.50		3.50		3.50	
Displacement, cu in.	110		110		110		110	
Surface/Volume, 1/in.	5.23		5.23		5.23		-	
Compression Ratio	8.0		8.0		8.0		8.9	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	62.5 at 5000[a, b]		67.5 at 5000[a, c]		68.5 at 5000[a, c] 78.5 at 5000[c, d]		-	
Torque, ft-lb, at Engine Speed, rpm	86 at 2500[a, b]		87 at 2750[a, c]		87 at 2750[a, c] 94 at 3000[c, d]			
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Bathtub		Bathtub		Bathtub		Heart shaped	
Intake Valve Diameter, in.	1.56		1.56		1.625		-	
Intake Valve Lift, in.	0.36		0.36		0.36		-	
Exhaust Valve Diameter, in.	1.34		1.34		1.34		-	
Exhaust Valve Lift, in.	0.36		0.36		0.36		-	
Intake Valve Opens, deg BTC	5		5		16		-	
Intake Valve Closes, deg ABC	45		45		56		-	
Intake Valve Duration, deg	230		230		252		-	
Exhaust Valve Opens, deg BBC	51		51		51		-	
Exhaust Valve Closes, deg ATC	21		21		21		-	
Exhaust Valve Duration, deg	252		252		252		-	
Valve Overlap, deg	26		26		37		-	
Distributor Type	Breakerless; centrifugal advance		Breaker point; centrifugal advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance	
Basic Ignition Advance, deg BTC, at Engine Speed, rpm	10 at 1500		13 at 1500		12 at 1500[a] 11 at 1500[d]		20 at 1000[e] 12 at 600[f]	
Idle Speed, rpm	850		850		850		900[e] 800[f]	
Fast Idle Speed, rpm							1350	
Intake Air Temperature Control	Thermostatic		Thermostatic		Thermostatic		-	
Fuel System Type	1V sidedraft carburetor		1V sidedraft carburetor		1V sidedraft, 1 or 2 carburetors		-	
Fuel Metering Method	Variable orifice metering needle		Variable orifice metering needle		Variable orifice metering needle		-	
Enrichment Method	Oil damper on air valve		Oil damper on air valve		Oil damper on air valve		-	
Choke Type	Automatic, bimetal		Automatic, bimetal		Manual			
Carburetor Venturi Diameter, in.	1.75		1.75		1.75[a] 1.5[d]		-	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	125 at 0.65		125 at 0.65		188 at 1.1[a] 127 at 1.0[d]		-	
Emission Control Systems	AIR CAT EGR EVAP PCV		AIR CAT[b] EGR EVAP PCV		AIR EVAP PCV		AIR EM EVAP PCV	
Emission Control Devices	Antirunon valve EGR service indicator Gulp valve Heated intake air Throttle bypass valve		Antirunon valve EGR service indicator Gulp valve Heated intake air Throttle bypass valve		Antirunon valve Heated intake air Gulp valve Throttle bypass valve		-	

[a] One single-venturi carburetor (used with Austin Marina)

[b] California vehicles only

[c] 49-States vehicles only

[d] Two single-venturi carburetors (used with MGB)

[e] MGB

[f] Austin Morris

design parameters. The change in surface-to-volume ratio shown in Table 5-7 is associated with the 1976 increase in compression ratio, and valve overlap is unchanged for the 1974 through 1976 model years. Addition of secondary air in 1975 and an oxidizing catalyst on California vehicles in 1976 are significant external additions that have allowed maintenance of the basic engine parameters over recent model years. On the high-compression 49-states engine, the requirement for leaded fuel is accommodated by deleting the catalyst required to meet the more stringent HC and CO standards of California.

5.3.3.2 Intake System

As indicated in Table 5-7, thermostatic control of carburetor intake air is used on the subject engine. The system is a conventional one, using a mixture of exhaust manifold-heated and ambient underhood air to maintain carburetor intake air at approximately 100°F.

5.3.3.3 Carburetor

5.3.3.3.1 Design Features

The subject engine employs a single-venturi sidedraft carburetor which maintains a constant depression at the fuel nozzle by dynamically adjusting the carburetor's effective venturi area as a function of total air mass flow rate. Fuel metering is implemented by a fixed orifice and a tapered needle which is attached to the air valve controlling the effective venturi area. Changes in air/fuel ratio, resulting from fuel temperature changes, are compensated by a bimetallic device which adjusts the position of the fuel orifice.

As indicated in Table 5-7, the 91-CID engine uses a device to cut off fuel flow to the carburetor and thus prevent dieseling after ignition shutoff. Dieseling is prevented by a solenoid-actuated anti-runon valve which applies vacuum to the carburetor float bowl via the charcoal canister of the evaporative emission control system. Vacuum is applied to the float bowl when the ignition is shut off and is removed as engine oil pressure approaches zero. Application of vacuum to the float bowl causes fuel flow in the carburetor to cease because the float bowl and carburetor venturi are subjected to approximately the same pressure under these conditions; therefore, no venturi float bowl pressure differential is available to cause fuel to flow. During the time the valve applies vacuum to the float bowl, the canister purge line to the carburetor is blocked so that fuel vapors cannot be supplied to the carburetor from the canister.

The subject engine also employs a throttle air bypass valve (ABPV) to promote oxidation of fuel-rich mixtures during deceleration. The valve is implemented as a spring-loaded throttle plate disc which opens when intake manifold vacuum reaches 21.5-in. Hg.

5.3.3.3.2 Carburetor Calibration

Carburetor air fuel ratio versus air flow data for the subject engine are presented in Table 5-9. As seen in the table, California carburetors are set slightly richer for a given vehicle type. This is most likely done in order to enhance post-combustion oxidation of HC and CO.

5.3.3.4 Ignition System

5.3.3.4.1 Design Features

A breakerless ignition system has been introduced in 1975 for use on the 91-CID engine. This system is implemented by a distributor-mounted timing rotor, a pickup module, a power transistor, and an ignition coil. The system operates by causing ferrite rods in the timing rotor to pass a coil in the pickup module. This causes an oscillator in the pickup module to momentarily break into a high-frequency oscillation. The high-frequency oscillation is used as a signal to turn off the power transistor which controls primary current in the ignition coil. Thus, a break in the primary circuit of the ignition coil occurs each time a ferrite rod passes the pickup coil. The resulting high voltage in the secondary circuit is used to fire the spark plugs as in conventional breaker-point ignition systems.

5.3.3.4.2 Spark Advance Schedules

Table 5-9 presents basic timing and centrifugal spark advance schedules used with the subject engine. Vacuum advance is not used and spark retard, which is effective only for low loads, at idle, and during deceleration, is set at approximately 10-12 crankshaft deg maximum. As shown in the table, centrifugal advance is unchanged, except for a decrease from 1974 to 1975 at medium-to-high engine speeds. This measure was adopted to meet the 1975 HC and NO_x requirements.

TABLE 5-9. CERTIFICATION CALIBRATION DATA: BRITISH LEYLAND 91-CID ENGINE

Engine/Vehicle Parameter[a]	Model Year and Certification Standard									
	1976 49 States		1976 California		1975 49 States		1975 California		1974 49 States and California	
Vehicle Model	T[b]	G[c]	T[b,d]	G[c,d]	T[b]	G[c]	T[b]	G[c]	T[b]	G[c]
Transmission Type	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4
Vehicle Inertia Weight, lb	2000	2000	2250	2250	2250	2250	2250	2250	2000	2000
Rear Axle Ratio	3.89	3.91	3.89	3.91	3.89	3.91	3.89	3.91	3.89	3.89
Catalyst	No	No	Yes	Yes	No	No	Yes	Yes	No	No
No. of Carburetor Venturi's	1	1	1	1	1	1	1	1	1	1
Carburetor Calibration, A/F										
Idle: 0.5-lb/min air flow	12.5	11.0	12.2	-	12.5	11.0	12.2	-	-	-
Off Idle: 1.0-lb/min air flow	13.5	13.1	13.0	-	13.5	13.1	13.0	-	-	-
Part Throttle: 3.0-lb/min air flow	18.2	16.5	16.5	-	18.2	16.5	16.5	-	-	-
WOT at Max.: 9.0-lb/min air flow	-	-	-	-	-	-	-	-	-	-
Basic Timing, crankshaft deg BTC	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Centrifugal Advance, crankshaft deg										
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	6.5	6.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
2000 rpm	9.0	9.0	11.5	11.5	11.5	11.5	11.5	11.5	14.5	14.5
3000 rpm	12.5	12.5	14.0	14.0	14.0	14.0	14.0	14.0	16.5	16.5
4000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	20.0	20.0
5000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	20.0	20.0
EGR Valve Calibration										
Signal Pressure To Open, mm Hg	112	112	112	112	112	112	112	112	-	-
Flow at 350-mm Hg, kg/hr	9.75	9.75	19.5	19.5	9.75	9.75	19.5	19.5	-	-
Fuel Economy, mpg										
City	25	25	25	21	22	21	25	21	23.1[e]	22.3[e]
Highway	37	37	31	30	33	30	31	30	-	-
Exhaust Emissions, g/m										
HC	1.5	0.9	0.5	0.4	0.9	1.5	0.5	0.4	3.2[e]	2.9[e]
CO	13.0	11.0	2.4	2.5	9.0	8.0	2.4	2.5	28.0[e]	27.0[e]
NO_x	1.4	1.6	1.5	1.4	2.8	1.6	1.5	1.4	1.5[e]	1.3[e]

[a] Vacuum advance is not used.

[b] Triumph Spitfire

[c] MG Midget

[d] 1975 carryover

[e] 1972 FTP

5.3.3.5 Exhaust Gas Recirculation

5.3.3.5.1 Design Features

EGR is used on the 91-CID engine as indicated in Tables 5-7 and 5-9. The EGR valve is vacuum-controlled with the control signal taken from a carburetor throttle edge port which gives no EGR at idle or full load. Intermediate loads cause an amount of EGR, which is dependent on the vacuum signal and EGR valve metering profile. In manual choke 91-CID engines, an EGR cutout valve blocks the signal to the EGR valve when the choke is in operation. This is implemented by an air bleed in the EGR vacuum line.

5.3.3.5.2 EGR Valve Calibration

Table 5-9 presents EGR valve calibration data. As shown in the table, considerably higher valve flow rates are used for California as opposed to 49-states vehicles in order to meet the more stringent California NO_x standards.

5.3.3.6 Secondary Air Injection

To assist in the control of HC and CO, a conventional secondary air injection system is used for the model years indicated in Table 5-7. This system is composed of a vane-type air pump, check valve, diverter valve, and manifold distribution system.

5.3.3.7 Catalytic Converter

An oxidizing catalytic converter is used on the 1976 California 91-CID engine. Construction is of the extruded monolith type for the substrate, and active materials are approximately 92.5 percent platinum and 7.5 percent rhodium. The 4.5-pound unit is cylindrical, 10 inches long and 4.25 inches in diameter. Active surface area is approximately 2690 sq in. and no warning system for catalyst protection is used.

5.3.3.8 Crankcase and Evaporative Emission Control

Conventional closed crankcase and evaporative emission control systems similar to those described in Section 3 are used on the subject engine. The "constant" depression area of the carburetor provides the source for crankcase vacuum, and evaporative emission control is achieved by venting the fuel tank and carburetor float bowl to atmosphere through an absorption canister with a filter constructed of activated charcoal. Crankcase depression is used to purge the filter when the engine is running.

5.3.3.9 Fuel Economy and Emissions

Fuel economy and emission data for the 1974-1976 model 49-states and California certification vehicles are listed in Table 5-9 (Refs. 5-8 through 5-13 and 5-29). The normalized city fuel economy curve based on these data and the certification data in Ref. 5-20 are presented in Figure 5-8. The data presented are normalized to a standard axle ratio and inertia weight in order to place all data on an equivalent basis. Section 3 describes the normalization procedure.

As seen in Figure 5-8, the 49-states vehicles with a 91-CID engine exhibit declining fuel economy between the 1973 and 1975 model years. As the 1974 model 49-states vehicles shown in Table 5-9 are certified to the more stringent 1974 California NO_x emission requirement, the 1973/1974 portion of the subject fuel economy decline is attributed to measures taken to meet the 1974 California standard. The 1974 to 1975 decline of the 49-states fuel economy is correlated with and attributed to a decrease in centrifugal spark advance, which is shown in Table 5-9. A sharp rise in the fuel economy of the 49-states vehicle between 1975 and 1976 is attributed to the previously described increase in compression ratio from 7.5:1 in 1974 to 9.1:1 in 1976. This change occurs between years when the calibration data of Table 5-9 show no change.

California vehicle fuel economy between the 1974 and 1976 model years remains flat. This is expected as the 1976 certification vehicles are 1975 carryovers. However, the unchanged fuel economy between 1974 and 1975 does not correlate well with decreased 1974 to 1975 centrifugal advance shown in Table 5-9. As the decline is well within the test-to-test error tolerance band, the lack of correlation may be attributed to random test and hardware variations.

5.3.4 British Leyland 110-CID Engine

5.3.4.1 Engine Modifications

For the model years shown in Table 5-8, British Leyland uses a bathtub combustion chamber with a 5.23 $in.^{-1}$ surface-to-volume ratio.

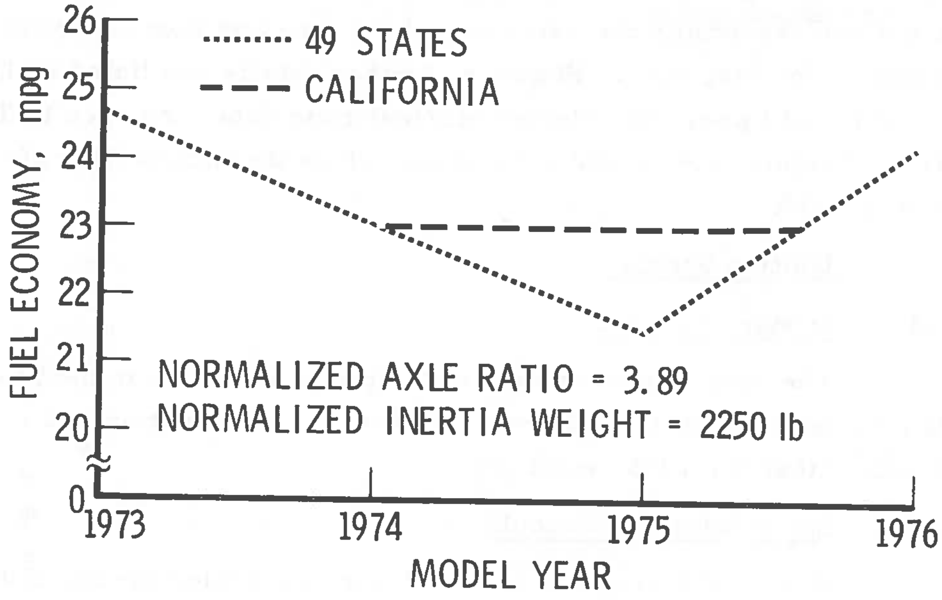


FIGURE 5-8. NORMALIZED AVERAGE CITY FUEL ECONOMY: BRITISH LEYLAND 91-CID ENGINE

The compression ratio is 8.0:1, down from 8.9:1 in 1970.

Changes from 1974 to 1975 in valve timing on the 110-CID engine have resulted in a decrease in the amount of intake valve opening advance. Coupled with the introduction of catalytic converters on California vehicles in 1975 and 49-states vehicles in 1976, this indicates a reduction of the HC and CO emission control burden on the engine.

5.3.4.2 Intake System

Thermostatic control of inlet air to the carburetor is employed as indicated in Table 5-8. The system is a conventional one, consisting of a thermostatically controlled flap valve and an exhaust manifold air heater.

5.3.4.3 Carburetor

The 110-CID engine employs a single-venturi sidedraft carburetor of the same general configuration used on the 91-CID engine. As the two systems are essentially the same except for size and flow capability, the 110-CID unit is not described. However, further details are listed in Table 5-8, and Table 5-10 presents selected air/fuel ratio data. As seen in Table 5-10, air/fuel ratios have tended to be leaner since the introduction of catalytic converters in 1975.

5.3.4.4 Ignition System

5.3.4.4.1 Design Features

The breakerless system described previously for the 91-CID engine is also used on the 110-CID model; however, introduction was made in the 1976 rather than the 1975 model year.

5.3.4.4.2 Spark Advance Schedule

Table 5-10 presents spark advance schedules for the 110-CID engine. As on the 91-CID engine, vacuum advance is not used in recent model years; however, in and prior to 1974 vacuum advance is used. Vacuum retard is not employed.

5.3.4.5 Exhaust Gas Recirculation

The same basic EGR system described previously for the 91-CID engine is used on the 110-CID model. Available valve calibration data are given in Table 5-10.

5.3.4.6 Secondary Air Injection

A generally conventional secondary air injection system is incorporated on the 110-CID engine. However, a slight departure from methods used by domestic manufacturers is taken to control pump air flow. On the 110-CID engine, under conditions of rapid throttle closure, pump air flow to the exhaust ports is reduced to prevent backfire caused by a temporarily fuel-rich mixture in the exhaust stream. The reduction is achieved by use of a gulp valve actuated by a rapid rise in intake manifold vacuum. Opening of the gulp valve ducts part of the pump output to the inlet manifold via a restrictor.

TABLE 5-10. CERTIFICATION CALIBRATION DATA: BRITISH LEYLAND 110-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard								
	1976 49 States and California[a]		1975 49 States		1975 California[a]		1974 49 States and California		1970
Vehicle Model	M[b,c]	M[b,c]	M[b]	A[d]	M[b]	A[d]	M[b]	GT[e]	M[f]
Transmission Type	M4	M4-OD	M4	M4	M4	M4	M4	M4	M4
Vehicle Inertia Weight, lb	2500	2500	2500	2500	2500	2500	2500	3000	-
Rear Axle Ratio	3.91	3.91	3.91	3.64	3.91	3.64	3.91	3.91	3.91
Catalyst	Yes	Yes	No	No	Yes	Yes	No	No	No
No. of Carburetor Venturi's	1	1	1	1	1	1	2x1V	2x1V	-
Carburetor Calibration, A/F									
Idle: 0.5 lb/min air flow	11.1	11.1	-	-	11.1	11.3	9.5	9.5	-
Off Idle: 1.0 lb/min air flow	12.8	12.8	-	-	12.8	12.5	10.5	10.5	-
Part Throttle: 3.0 lb/min air flow	18.2	18.2	-	-	18.2	16.5	12.1	12.1	-
WOT at Max.: lb/min air flow	-	-	-	-	-	-	-	-	-
Basic Timing, crankshaft deg BTC	10	10	-	-	13	13	11	11	10
Centrifugal Advance, crankshaft deg									
1000 rpm	0.0	0.0	-	-	0.0	0.0	0.0	0.0	0.0
1500 rpm	5.0	5.0	-	-	5.0	5.0	3.5	3.5	3.5
2000 rpm	10.0	10.0	-	-	10.0	10.0	9.0	9.0	10.0
3000 rpm	20.0	20.0	-	-	20.0	20.0	17.0	17.0	14.0
4000 rpm	30.0	30.0	-	-	30.0	30.0	26.5	26.5	18.0
5000 rpm	30.0	30.0	-	-	30.0	30.0	32.0	32.0	20.0
Vacuum Advance, crankshaft deg									
5 in. Hg	-	-	-	-	-	-	0	0	0
6 in. Hg	-	-	-	-	-	-	0	0	5.0
8 in. Hg	-	-	-	-	-	-	0	0	11.0
10 in. Hg	-	-	-	-	-	-	0	0	15.0
12 in. Hg	-	-	-	-	-	-	5.5	5.5	18.5
15 in. Hg	-	-	-	-	-	-	10.0	10.0	20.0
20 in. Hg	-	-	-	-	-	-	10.0	10.0	20.0
EGR Valve Calibration									
Signal Pressure To Open, in. Hg	-	-	-	-	-	-	-	-	-
Flow at 9-in. Hg, lb/hr	48	48	-	-	48	-	-	-	-
Fuel Economy, mpg									
City	16	16	18	22	16	-	18.7[g]	16.3[g]	-
Highway	23	30	27	28	23	-	-	-	-
Exhaust Emissions, g/m									
HC	0.2	0.2	-	-	0.2	-	-	-	-
CO	5.6	5.6	-	-	5.6	-	-	-	-
NO_x	1.2	1.2	-	-	1.2	-	-	-	-

[a] Vacuum advance is not used.
[b] MGB convertible
[c] 1975 carryover
[d] Austin Marina
[e] MGB GT
[f] MGB
[g] 1972 FTP

This is done on a time cycle proportional to the change in vacuum. A gulp valve open duration of approximately 1.6 seconds results for an intake manifold vacuum of 20-in. Hg. The net result is that air delivery to the exhaust ports is reduced and the diverted air is used to dilute the rich mixture in the inlet manifold. Generally, domestic manufacturers merely divert pump air to the atmosphere during deceleration as British Leyland does in its 91-CID engine.

5.3.4.7 Catalytic Converter

The system used on the 110-CID engine is essentially identical to the one described for the 91-CID engine.

5.3.4.8 Crankcase and Evaporative Emission Control

The systems for the 110-CID engine are similar to the ones described for the 91-CID engine.

5.3.4.9 Fuel Economy and Emissions

Data on fuel economy and emissions for the 1974-1976 49-states and California certification vehicles are listed in Table 5-10. (Refs. 5-9 through 5-13 and 5-29). Figure 5-9 presents a normalized city fuel economy curve based on these data and on data in Ref. 5-20. Section 3 describes the normalization rationale and process.

As shown in Figure 5-9, the 49-states and California fuel economy is unchanged between 1973 and 1974. This is unusual as the subject certification vehicles have been qualified to more stringent standards in 1974 than in 1973, and a decline in fuel economy would normally be expected.

The sharp 1974 to 1975 decline in fuel economy of the California vehicles is well correlated with the deletion of vacuum advance in 1975. Unfortunately, calibration data for 1975 model 49-states vehicles are not available; therefore, the 1974 to 1975 fuel economy trends for these vehicles cannot be rationalized in terms of engine control system changes. The fuel economy in 1975 and 1976 is identical and explained by noting that the 1976 California and 49-states certification vehicles shown in Figure 5-9 and in Table 5-10 are simply carryovers of the 1975 California vehicles.

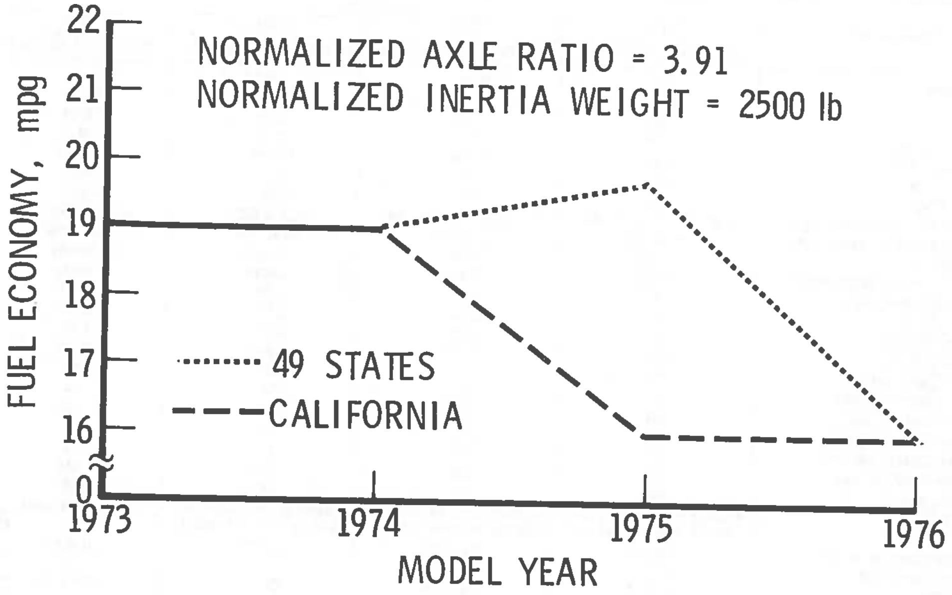


FIGURE 5-9. NORMALIZED AVERAGE CITY FUEL ECONOMY: BRITISH LEYLAND 110-CID ENGINE

5.4 FIAT

5.4.1 Engine/Vehicle Configurations

The Fiat 78.7 CID overhead cam engine is the unit selected to represent contemporary Italian engine control practices used on vehicles built for sale in the United States. The engine is teamed with a four-speed transmission and used in the 128 series of vehicles rated at 2250- and 2500-pound inertia weight. This series includes two- and four-door sedans, a coupe, and a station wagon. In addition, the engine is used with the Fiat X1/9 mid-engine sport car, which is placed in the 2250-pound inertia weight class in 1974 and in the 2500-pound class in 1975 and 1976.

5.4.2 Engine Design Features

Table 5-11 presents an overview of the subject engine's design features (Refs. 5-30 through 5-40). Model years of interest are 1972 and

TABLE 5-11. ENGINE SPECIFICATIONS: FIAT 79-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4	
Bore, in.	3.39		3.39		3.39		3.39	
Stroke, in.	2.19		2.19		2.19		2.19	
Displacement, cu in.	78.7		78.7		78.7		78.7	
Surface/Volume, 1/in.	11.059		11.059		11.059		11.059	
Compression Ratio	8.5		8.5		8.5		8.5	
Cylinder Head Type	OHC		OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	62 at 6000	61 at 5800	62 at 6000	61 at 5800	66.5 at 6200		54 at 5600	
Torque, ft-lb, at Engine Speed, rpm	67 at 4000		67 at 4000		68 at 3600		54 at 3000	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.42		1.42		1.42		1.42	
Intake Valve Lift, in.	0.347		0.347		0.347		0.347	
Exhaust Valve Diameter, in.	1.22		1.22		1.22		1.22	
Exhaust Valve Lift, in.	0.343		0.343		0.343		0.343	
Intake Valve Opens, deg BTC	10		10		10		10	
Intake Valve Closes, deg ABC	54		54		54		54	
Intake Valve Duration, deg	244		244		244		244	
Exhaust Valve Opens, deg BBC	54		54		54		54	
Exhaust Valve Closes, deg ATC	10		10		10		10	
Exhaust Valve Duration, deg	244		244		244		244	
Valve Overlap, deg	20		20		20		20	
Distributor Type	Breaker point; centrifugal advance, vacuum retard		Breaker point; centrifugal advance, vacuum retard		Breaker point; centrifugal advance, vacuum retard		Breaker point	
Basic Ignition Advance, deg BTC, at Engine Speed, rpm	0 at 850		0 at 850		0 at 850		0 at 850	
Idle Speed, rpm	825 ± 25		825 ± 25		825 ± 25		825 ± 25	
Fast Idle Speed, rpm	-		-		-		-	
Intake Air Temperature Control	None		None		None		None	
Fuel System Type	1V carburetor		1V carburetor		1V carburetor		1V carburetor	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Fixed orifice; acceleration pump		Fixed orifice; acceleration pump		Fixed orifice; acceleration pump		-	
Choke Type	Automatic		Automatic		Manual		Manual	
Carburetor Venturi Diameter, in.	0.865 (each)		0.865 (each)		0.865 (each)		0.91 (each)	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	105 at 1.34		105 at 1.35		140 at 1.4		-	
Emission Control Systems	AIR CAT[a] EVAP PCV	AIR CAT EVAP PCV	AIR CAT[a] EVAP PCV	AIR CAT EVAP PCV	AIR EVAP PCV		EM EVAP PCV	
Emission Control Devices	CAT fuel shutoff protection[a] Cold engine advance delay COS Cold engine air COS Throttle damper Transmission advance delay COS Vacuum ignition advance delay		CAT fuel shutoff protection[a] Cold engine advance delay COS Cold engine air COS Throttle damper Vacuum ignition advance delay		Cold engine delay COS Vacuum ignition advance delay		Throttle closing limiter	

[a] Only on X 1/9 vehicles

1974-1976. As shown in Table 5-11, the 78.7-CID Fiat engine remains essentially unchanged in basic engine design parameters since its introduction in 1972. Changes in engine controls over the years have been implemented primarily by application of systems and devices external to the engine.

5.4.3 Engine Modifications

One of the more notable parameters characterizing the subject engine is a surface-to-volume ratio of 11.059 in^{-1}. This is unusually large compared with most contemporary automobile engines, which generally have a surface-to-volume ratio of approximately 6 in^{-1}.

Another engine design parameter that is somewhat high compared to current practice is the compression ratio, which is set at 8.5. While this magnitude is not exceptional by itself the fact that it is used on an engine which does not employ EGR is somewhat unusual. However, 20 deg of intake exhaust valve overlap is used, and this provides a measure of charge dilution often achieved by using EGR on other engines with less overlap. Also, as discussed in Section 5.4.5, ignition vacuum retard is used, and this further aids control of NO_x emissions. Finally, the small engine displacement and the light weight of the vehicles in which it is used contributes to lower emissions, on a grams per mile basis and allows use of simpler control techniques.

5.4.4 Intake System

Fiat employs a conventional dry paper filter and ambient underhood air system. Thermostatic control of intake air is not used in this engine.

5.4.5 Carburetor

5.4.5.1 Design Features

For the 1974-1976 model years, Fiat uses a conventional two-venturi downdraft carburetor calibrated for optimum post-combustion of exhaust gases by the secondary air injection system. On 1975 and 1976 models, the idle jet fuel supply is controlled by an idle stop solenoid which cuts off fuel to the carburetor when the ignition switch is turned off. In addition, a dashpot is used to control the closing rate of the throttle during deceleration. In 1972, a two-venturi carburetor with slightly larger venturis was used. A throttle limiting device which limits throttle closure to the fast idle position during deceleration is employed to maintain low HC and CO emissions.

5.4.5.2 Carburetor Calibration

Table 5-12 presents air/fuel ratio data at four carburetor air flow rates. As seen in the table, a trend toward leaner part-throttle operation is noticable between 1972 and 1976. Also, within the 1975 and 1976 model years, the same carburetor settings are used for catalyst and non-catalyst vehicles although the air/fuel ratio does change from year to year.

5.4.6 Ignition System

5.4.6.1 Design Features

In 1975, Fiat listed a breakerless ignition system in its initial application for certification to both the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB). However, the system is not listed in the 1976 documentation, and subsequent checks have revealed that a conventional breaker-point system is in service on all 1975 and 1976 model year versions of the subject engine. As the system is conventional, it is not described in detail. However, it is noted that vacuum ignition retard is used in conjunction with centrifugal advance and that vacuum advance is not used.

Retard is set at 10 crankshaft deg maximum, is normally active at idle, and is reduced to zero as the throttle opens. However, under certain conditions, retard is also active for approximately 7 seconds following initial opening of the throttle. The delayed reduction of vacuum retard following throttle opening is controlled by a pneumatic device in the vacuum line between the carburetor vacuum port and the distributor retard diaphragm. It, in turn, is controlled by a thermovalve sensitive to engine coolant temperature and, on 1976 models, by a solenoid operated valve which is actuated by the transmission gear selector. Both of these devices defeat the retard delay device under certain conditions. The thermovalve defeats retard delay when engine coolant is below $62.5 \pm 5^{\circ}F$, and the solenoid controlled valve defeats the delay device when the transmission is in fourth gear. Thus, only for cold engine or fourth gear operation is reduction of vacuum retard (a relative vacuum advance) immediate upon opening of the throttle.

Ignition centrifugal and vacuum curves have a ±1.5 crankshaft deg tolerance band over most of their operating range with the centrifugal curve tolerance expanding to ±2.0 crankshaft deg at engine speeds below approximately 1800 rpm.

TABLE 5-12. CERTIFICATION CALIBRATION DATA: FIAT 79-CID ENGINE

Engine/Vehicle Parameter[a]	Model Year and Certification Standard																
	1976 49 States				1976 California					1975 49 States		1975 California		1974 49 States and California			1972 and 1973 49 States and California
Vehicle Model	F[b]	F[b,c]	F[d]	F[c,e]	F[e]	X[f]	F[d]	F[b]	X[f]	F[e]	F[b]	F[b,c]	F[b,g]	X[f]	F[d]	F[b]	F[b]
Transmission Type	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4	M4
Vehicle Inertia Weight, lb	2250	2500	2500	2500	2250	2500	2500	2500	2500	2500	2500	2500	2500	2250	2250	2250	2250[h]
Rear Axle Ratio	4.42	4.42	4.42	4.42	4.08	4.08	4.08	4.42	4.42	4.42	4.42	4.42	4.42	4.08	4.42	4.08	4.08[h]
Catalyst	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Carburetor Calibration, A/F																	
Idle: 11-kg/hr Air Flow	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.6	13.6	13.6	12.6
Off Idle: 23-kg/hr Air Flow	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	13.5	13.5	13.5	13.5	13.9	13.9	13.9	13.2
Part Throttle: 40-kg/hr Air Flow	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	16.3	16.3	16.3	16.3	16.0	16.0	16.0	15.8
WOT at Max: 275-kg/hr Air Flow	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.5	14.5	14.5	-
Basic Timing, crankshaft deg BTC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centrifugal Advance, crankshaft deg																	
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
1500 rpm	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	20.0
2000 rpm	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	24.0
3000 rpm	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	29.5
4000 rpm	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	35.0
5000 rpm	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	38.0
Fuel Economy, mpg																	
City	20	19	20	21	22	23	20	20	19	21	19	20	19	20.4[i]	17.8[i]	17.4[i]	21.2[h,i]
Highway	32	28	31	29	35	33	29	28	28	29	28	28	28	-	-	-	-
Exhaust Emissions, g/m																	
HC	1.2	0.7	1.2	0.6	0.2	0.2	0.3	0.4	0.1	0.6	0.7	-	-	-	-	-	1.6[h,i]
CO	10.0	11.0	8.0	12.0	2.6	3.0	3.1	3.6	4.1	12.0	11.0	-	-	-	-	-	21.0[h,i]
NO_x	1.9	1.6	2.0	1.5	1.2	1.9	1.5	1.2	1.1	1.5	1.6	-	-	-	-	-	2.0[h,i]

[a] Vacuum advance is not used; EGR is not used

[b] 128 Sedan

[c] 1975 Carryover

[d] 128 Station wagon

[e] 128 Coupe

[f] X19

[g] Also offered as a 49-states vehicle

[h] 1973 Vehicle

[i] 1972 FTP

5.4.6.2 Ignition Advance

Table 5-12 presents ignition spark advance for the 1972 and 1974-1976 model years. As may be seen in the table, no change occurs in spark advance from 1974 to 1976. However, a substantial decline occurs in centrifugal advance between 1973 and 1974.

5.4.7 Exhaust Gas Recirculation

Fiat does not use EGR on the subject engine.

5.4.8 Secondary Air Injection

A conventional secondary air injection system is used on the subject engine. In addition, a secondary air, cold temperature cutout is implemented, using an engine coolant temperature sensor and a switch to sense transmission gear selection. For engine coolant temperatures below approximately 75°F and with the transmission in neutral, a solenoid causes the diverter valve to dump air pump output to atmosphere. The function of the air cutout is to maintain the temperature in the exhaust system within acceptable limits.

5.4.9 Catalytic Converter

The catalyst used on all California vehicles and on the 49-states X1/9 model vehicles is based on a pellet substrate and is conventional with the exception of a catalyst warning system (CWS). The warning system consists of a control unit and a thermocouple located inside of the converter. For temperatures of the substrate equal to 1800 ±90°F, the control unit intermittently flashes a light on the vehicle dash which advises the vehicle driver to slow down. Frequency of signal light flashing increases as temperature increases, and a 122 ± 18°F hystersis is built into the system. Accidental failure of the thermocouple is indicated by continuous activation of the signal light.

In order to avoid excessive catalyst temperatures during decelerations, a solenoid-operated fuel shutoff to the carburetor is activated for engine speeds above 2650 ± 50 rpm while decelerating. A speed-sensitive switch is used to sense engine speed and enable the solenoid.

A mileage-actuated catalyst warning light completes the catalyst control system. This system actuates a light on the instrument panel at

25,000 vehicle miles to indicate the need for catalyst maintenance. The light remains on until manually reset.

5.4.10 Crankcase and Evaporative Emission Control

Fiat uses a conventional closed crankcase emission control system. The evaporative control system is based on a sealed system which vents the limited-fill tank and carburetor float bowl vapors to a charcoal canister in the engine compartment. These systems are similar to those described in Section 3.

5.4.11 Fuel Economy and Emissions

Table 5-12 lists fuel economy and emission data for the certification vehicles (Refs. 5-8 through 5-11, 5-13, and 5-29). Figure 5-10 presents a plot of city fuel economy versus model year with the data normalized to a standard axle ratio and inertia weight, using the procedure outlined in Section 3.

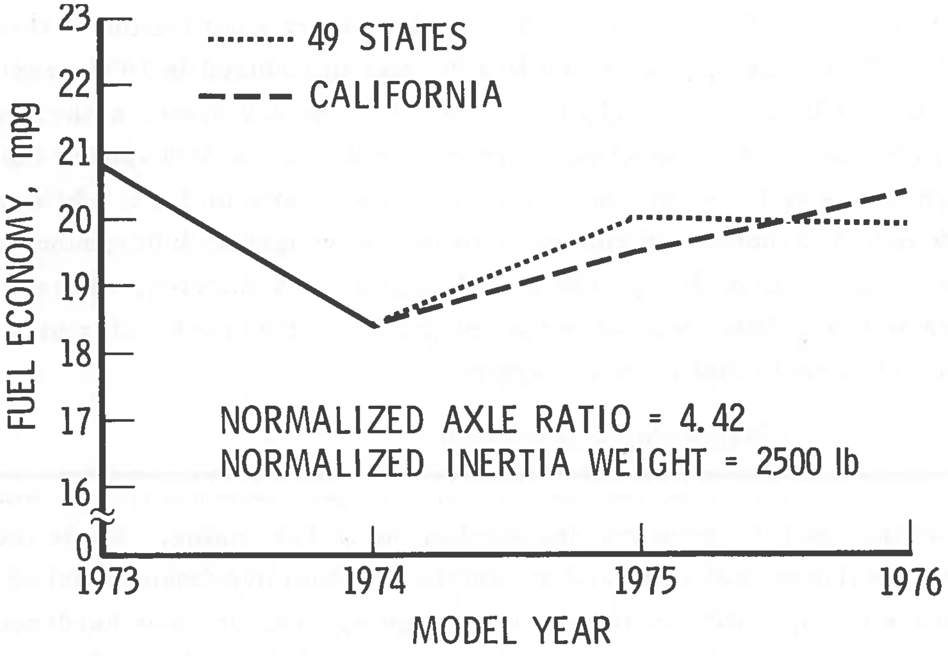


FIGURE 5-10. NORMALIZED AVERAGE CITY FUEL ECONOMY: FIAT 79-CID ENGINE

The 11 percent decline in fuel economy shown in Figure 5-10 between 1973 and 1974 may be attributed to the decrease in centrifugal spark advance shown in Table 5-12. Subsequent increases in fuel economy between 1974 and 1975 for both 49-states and California vehicles are difficult to rationalize as no calibration changes have been made over this time period except for minor carburetor readjustments. Fuel economy increases over this time period, as well as the small increase in fuel economy of California vehicles between 1975 and 1976, are therefore attributed to other factors, including test-to-test and vehicle-to-vehicle variabilities. Similar trends are obtained for highway fuel economy.

5.5 MERCEDES BENZ (DAIMLER BENZ A.G.)

5.5.1 Engine/Vehicle Configurations

The Mercedes Benz 6-cylinder, water-cooled, dual overhead cam 167.5 CID-engine has been selected for examination in this study. This engine, designated M 110, was introduced in 1973, replacing the 169.5-CID M 130 model as powerplant in the 280 series automobiles. All 1974 and earlier model year vehicles fall into the 3500-pound inertia weight class and are equipped with a rear axle ratio of 3.92, while the 1975 and 1976 model vehicles have an inertia weight of 4000-pounds and a rear axle ratio of 3.69. The M 110 engine is carbureted, whereas the older M 130 is fitted with either a Solex two-venturi carburetor or a Bosch electronic fuel injection system.

5.5.2 Engine Design Features

As shown in Table 5-13, a number of significant design modifications have been incorporated in the M 110 engine. These include a new hemispherical combustion chamber, a dual overhead camshaft to improve the operation of the valves at high speeds, and new hardened valve seats to permit engine operation on unleaded gasoline. In particular,

TABLE 5-13. ENGINE SPECIFICATIONS: MERCEDES BENZ 167.5-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	6		6		6		6	
Bore, in.	3.383		3.383		3.383		3.410	
Stroke, in.	3.102		3.102		3.102		3.102	
Displacement, cu in.	167.5		167.5		167.5		169.5	
Surface/Volume, 1/in.	5.17		5.17		5.17		6.8	
Compression Ratio	8.0		8.0		8.0		8.0	
Cylinder Head Type	Dual OHC		Dual OHC		Dual OHC		OHC	
Advertised HP at Engine Speed, rpm	120 at 5000		120 at 5000		130 at 5000		125 at 5200	
Torque, ft-lb, at Engine Speed, rpm	145 at 3600		145 at 3600		150 at 3500		141 at 4000	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Hemisphere		Hemisphere		Hemisphere		Wedge	
Intake Valve Diameter, in.	1.78		1.78		1.78		-	
Intake Valve Lift, in.	0.445		0.445		0.370		-	
Exhaust Valve Diameter, in.	1.461		1.461		1.461		-	
Exhaust Valve Lift, in.	0.414		0.414		0.370		-	
Intake Valve Opens, deg BTC	-6		-6		16	-6	16	
Intake Valve Closes, deg ABC	21		21		41	21	46	
Intake Valve Duration, deg	195		195		237	195	242	
Exhaust Valve Opens, deg BBC	30		30		55	30	53	
Exhaust Valve Closes, deg ATC	-13		-13		24	-13	15	
Exhaust Valve Duration, deg	197		197		259	197	248	
Valve Overlap, deg	None		None		40	None	31	
Distributor Type	Breakerless		Breakerless		Breakerless		Breaker point; transistorized	
Basic Ignition Advance, deg BTC	7		7		-4		-4	
Idle Speed, rpm	850		850		850	800	775	
Fast Idle Speed, rpm	1800		1800		2500		-	
Fuel System Type	4-V downdraft Solex		4-V downdraft Solex		4-V downdraft Solex		2-V downdraft or Bosch FI	
Fuel Metering Method	-		-		-		-	
Enrichment Method	-		-		-		-	
Choke Type	Automatic, electric assist		Automatic, electric assist		Automatic, electric assist		Automatic	
Carburetor Venturi Diameter, in.	0.787 at 2.13		0.787 at 2.13		0.787 at 2.13		-	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	210 at 0.35		210 at 0.35		210 at 0.35		-	
Emission Control Systems	AIR CAT EGR EVAP PCV		AIR CAT EGR EVAP PCV		EGR EVAP PCV	AIR EGR EVAP PCV TR[a]	EVAP PCV	
Emission Control Devices	Dashpot		Dashpot		Deceleration device[b] Spark retard		Deceleration device Spark retard	

[a] TR = thermal reactor

[b] 49-States vehicles only

the use of the hemispherical combustion chamber in place of the wedge employed in previous years has aided in the reduction of HC by lowering the surface-to-volume ratio of the combustion chamber from 6.8 to 5.17. As an additional emission control measure, the compression ratio has been reduced to 8.0 in 1972, from 9.0 and 9.5 used in the earlier carbureted and fuel injected configurations, respectively. Also, as described in the following subsections, a number of other component modifications and adjustments have been implemented over the years to meet the increasingly stringent emission control regulations. (Refs. 5-41 through 5-48).

5.5.3 Intake System

Intake manifold heating by means of engine coolant has been provided since 1974. In addition, all 1972-1976 model year engines are equipped with a temperature-controlled intake air heating arrangement similar to the systems used by other manufacturers.

5.5.4 Carburetor

5.5.4.1 Design Features

Most 1972 and earlier model year M 130 engines are equipped with a two-venturi downdraft carburetor of conventional design, using an electrically heated choke to reduce the cold start HC and CO emissions by accelerating choke opening. The choke operation is controlled by means of a bimetallic spring which is activated by two thermoswitches sensing coolant temperature and crankcase oil temperature. Electric choke heating is limited to coolant temperatures of 160°F and oil temperatures of 120°F.

A deceleration control unit is employed to assist in the control of HC and CO during vehicle deceleration. This device, which inhibits the formation of overly rich mixtures by preventing throttle closure to the idle position, consists of a solenoid-operated switching valve, a relay, two coolant temperature control switches, and a speed switch. For coolant temperatures between 65 and 212°F and engine speeds above 2000 rpm, both temperature switches and the speed switch are open, and the relay is closed. This energizes the switching valve admitting atmospheric pressure to a vacuum-operated governor which prevents complete closing of the throttle. Also, the solenoid valve is part of an anti-stall device which automatically opens the throttle slightly when engine speed drops below 600 rpm when the air conditioner (A/C) is in use at idle.

The Solex carburetor used in 1974 is similar to the Zenith unit, except for two additional venturi's, a needle valve-controlled main jet for the second stage, and a revised choke heating system to extend the heating time for oil temperatures below 63°F. Conversely, the deceleration device is eliminated in the California units, and the burden of HC and CO control is placed on the thermal reactor. Another addition to the California vehicles is the use of a special float chamber which is vented into the intake system and controlled by means of a vacuum-operated control valve.

The most significant carburetor modification implemented in 1975 is the addition of a choke bypass for cold start operation of the engine. This device, which consists of separate fuel and air metering systems, provides additional mixture into the carburetor downstream of the throttle plate. For normal engine operating temperatures, the device is deactivated by means of a thermostatically controlled valve. In addition, a manifold vacuum-controlled dashpot is used in 1975 which is designed to eliminate engine stalling at low speed and with the A/C in operation.

Except for small calibration variations, the 1976 carburetor is identical to the 1975 configuration.

5.5.4.2 Carburetor Calibration

Typical carburetor calibration data, exemplified by the 1976 model 49-states and California settings are presented in Figure 5-11, showing the air/fuel ratio band at part load as a function of carburetor air flow rate. At idle, the mixture is rich, followed by rapid leaning in the very low load regime and by near stoichiometric settings at part load.

Calibration data for other model years are listed in Table 5-14, in terms of part-load air/fuel ratio as a function of air flow. Compared with

TABLE 5-14. CERTIFICATION CALIBRATION DATA: MERCEDES BENZ 167.5-CID ENGINE WITH AUTOMATIC TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard								
	1976 49 States and California		1975 49 States and California		1974 49 States		1974 California		1972
Vehicle Inertia Weight, lb	4000	4000	4000	4000	3500	3500	3500	3500	-
Rear Axle Ratio	3.69	3.69	3.69	3.69	3.92	3.92	3.92	3.92	3.92
Catalyst	Yes	Yes	Yes	Yes	No	No	No	No	No
Carburetor Calibration, A/F									
Part Throttle: 20-kg/hr air flow	10.7	10.7	9.8	9.8	12.8	12.8	9.8	9.8	15.2
50-kg/hr air flow	12.8	12.8	12.3	12.3	13.7	13.7	11.5	11.5	16.7
100-kg/hr air flow	14.6	14.6	14.4	14.4	13.6	13.6	12.3	12.3	15.7
200-kg/hr air flow	14.7	14.7	14.5	14.5	13.3	13.3	12.3	12.3	-
260-kg/hr air flow	14.7	14.7	14.6	14.6	13.0	13.0	12.3	12.3	-
Basic Timing, crankshaft deg BTC	7	7	7	7	-4	-4	-4	-4	-4
Centrifugal Advance, crankshaft deg									
1000 rpm	0	0	0	0	0	0	0	0	0
1500 rpm	6	6	6	6	6	6	6	6	5
2000 rpm	11.5	11.5	11.5	11.5	12	12	12	12	10
3000 rpm	23	23	23	23	23	23	23	23	20
4000 rpm	25	25	25	25	30	30	30	30	24
5000 rpm	25	25	25	25	30	30	30	30	24
Vacuum Retard, crankshaft deg ATC									
2 in. Hg	0	0	0	0	0	0	0	0	-9
3 in. Hg	0	0	0	0	-6	-6	-6	-6	-18
4 in. Hg	0	0	0	0	-11	-11	-11	-11	-20
EGR Valve Calibration									
Signal Pressure To Open, in. Hg	2.8	2.8	2.8	2.8	-	-	-	-	0
Maximum Flow, kg/hr	53	53	53	53	-	-	-	-	0
Fuel Economy, mpg									
City	13	14	14	15	13.1[b]	14.1[b]	10.9[b]	11.3[b]	-
Highway	18	19	19	20	-	-	-	-	-
Exhaust Emissions, g/m									
HC	0.4	0.3	0.2	0.4	2.8[b]	2.4[b]	0.7[b]	0.7[b]	-
CO	3	2	4	4	23[b]	22[b]	19[b]	17[b]	-
NO_x	1.6	1.4	1.4	1.4	2.1[b]	1.6[b]	1.0[b]	1.5[b]	-

[a] No manual transmission certified.

[b] 1972 FTP.

most other manufacturers, Mercedes Benz uses somewhat richer mixtures in this engine.

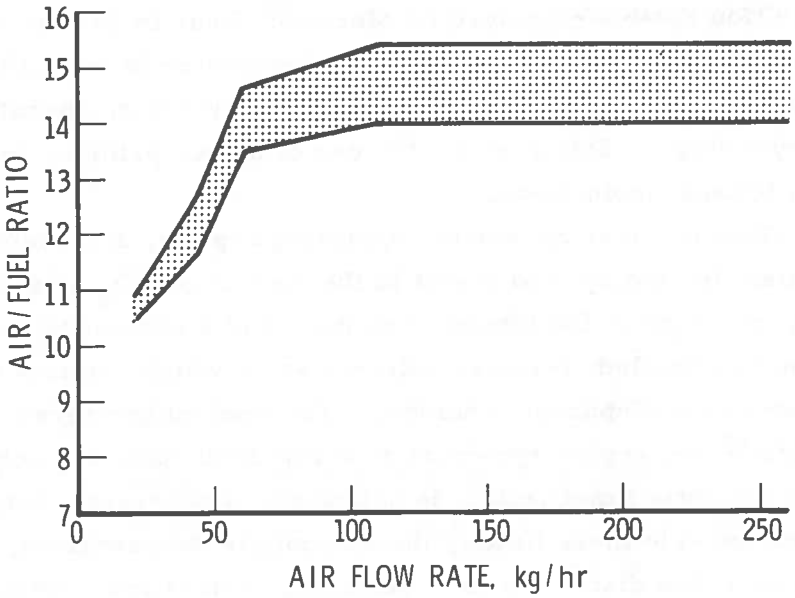


FIGURE 5-11. AIR/FUEL RATIO VERSUS AIR FLOW RATE: 1976 MERCEDES 167.5-CID ENGINE; CALIFORNIA AND 49-STATES CALIBRATION

Relative to 1972, the mixture is enriched in 1974, followed by moderately leaner mixtures in 1975 and 1976. Particularly, the use of a thermal reactor in 1974 requires rich mixtures to achieve the desired level of HC and CO emission control. Conversely, the use of a catalyst in 1975 and 1976 permits leaner mixture operation. As an aid in emission control, Mercedes Benz has reduced the calibration tolerances from about ±9 percent at idle in 1972, to about ±3.5 percent in 1975, and ±2.5 percent in 1976. At part load, the tolerance band has remained nearly constant at about ±5 percent during that time period.

5.5.5 Ignition System

5.5.5.1 Design Features

Except for the use of a transistorized primary ignition coil circuit, the ignition system employed by Mercedes Benz in 1972 is conventional, using mechanical breaker-points. The transistor is controlled by the breaker-points, which, unlike conventional ignition systems, operate under nominal battery voltage. This permits the use of higher primary voltage and results in less breaker-point wear.

Over much of the vehicle operating regime, a vacuum spark retard mechanism is employed to assist in the control of NO_x as well as HC and CO. Vacuum retard is implemented by means of a coolant temperature and engine speed controlled, two-way solenoid valve which controls the vacuum level in the distributor diaphragm chamber. For coolant temperatures between 63 and 212°F and engine speeds at or below 2000 rpm, the solenoid is energized, and the retard mechanism is activated. Conversely, for temperatures and speeds outside these limits, the solenoid is de-energized, admitting ambient pressure to the distributor and restoring normal spark advance settings.

The mechanical breaker-points have been replaced in 1974 by an inductive unit, and this configuration is retained in 1975 and 1976. This system is functionally identical to the design used by all United States manufacturers in 1976 and relies on conventional centrifugal and vacuum advance/retard mechanisms.

The ignition retard mechanism used in the 1974 model 49-states vehicles is similar to the 1972 configuration, except that the low-temperature switch senses oil temperature instead of coolant temperature. For oil temperatures above 63°F, coolant temperatures below 212°F, and engine speeds below 3400 rpm, the solenoid is energized, activating the retard mechanism. Outside these limits the retard mechanism is deactivated. In addition, spark retard is negated in fourth gear, at high engine loads (below 6-in. Hg vacuum), and when the air conditioner is turned on. Similar retard control settings are used in California except that retard is deactivated at coolant temperatures above 149°F instead of 212°F for the 49-states vehicles.

The ignition system used in 1975 and 1976 is identical to the 1974 design. However, incorporation of an oxidation catalyst permits complete deletion of spark retard. While this undoubtedly results in higher raw HC emissions from the engine, the catalyst efficiency is apparently sufficiently high to meet emission regulations with these vehicles.

5.5.5.2 Spark Advance/Retard Schedules

The spark advance and retard schedules used by Mercedes in the 1974 model 49-states and California vehicles is presented in Figure 5-12, showing centrifugal spark advance and vacuum retard in crankshaft deg as a function of engine speed. The centrifugal advance commences at about 1000 rpm and rises with increasing speed until a maximum value of 30 deg is reached at about 3500 rpm. The vacuum retard is constant (about 11 deg) over the entire operating regime of the engine, except at very low vacuum levels. It should be noted, however, that the retard is deactivated under certain conditions, as previously discussed.

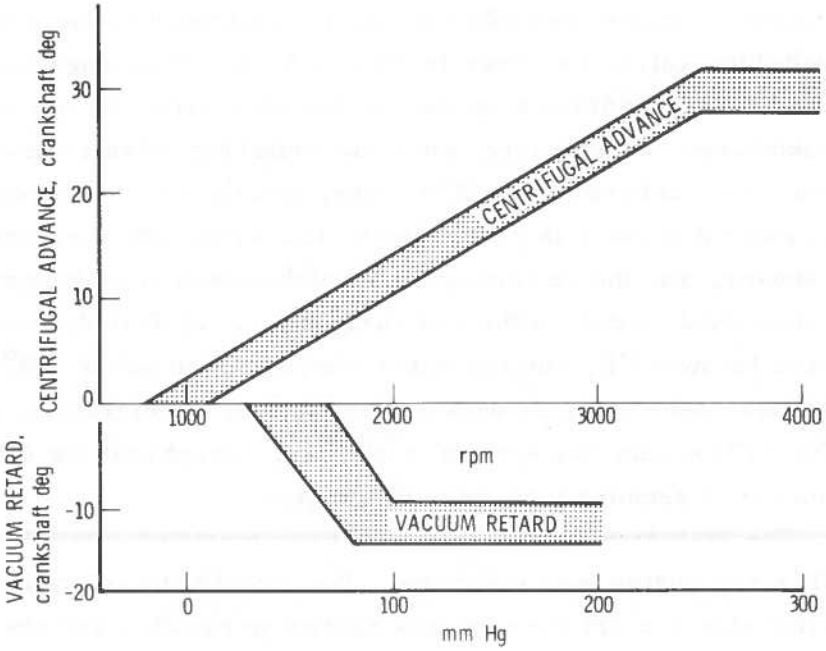


FIGURE 5-12. CENTRIFUGAL ADVANCE AND VACUUM RETARD SCHEDULES: 1974 MERCEDES 167.5-CID ENGINE; 49-STATES AND CALIFORNIA CALIBRATION

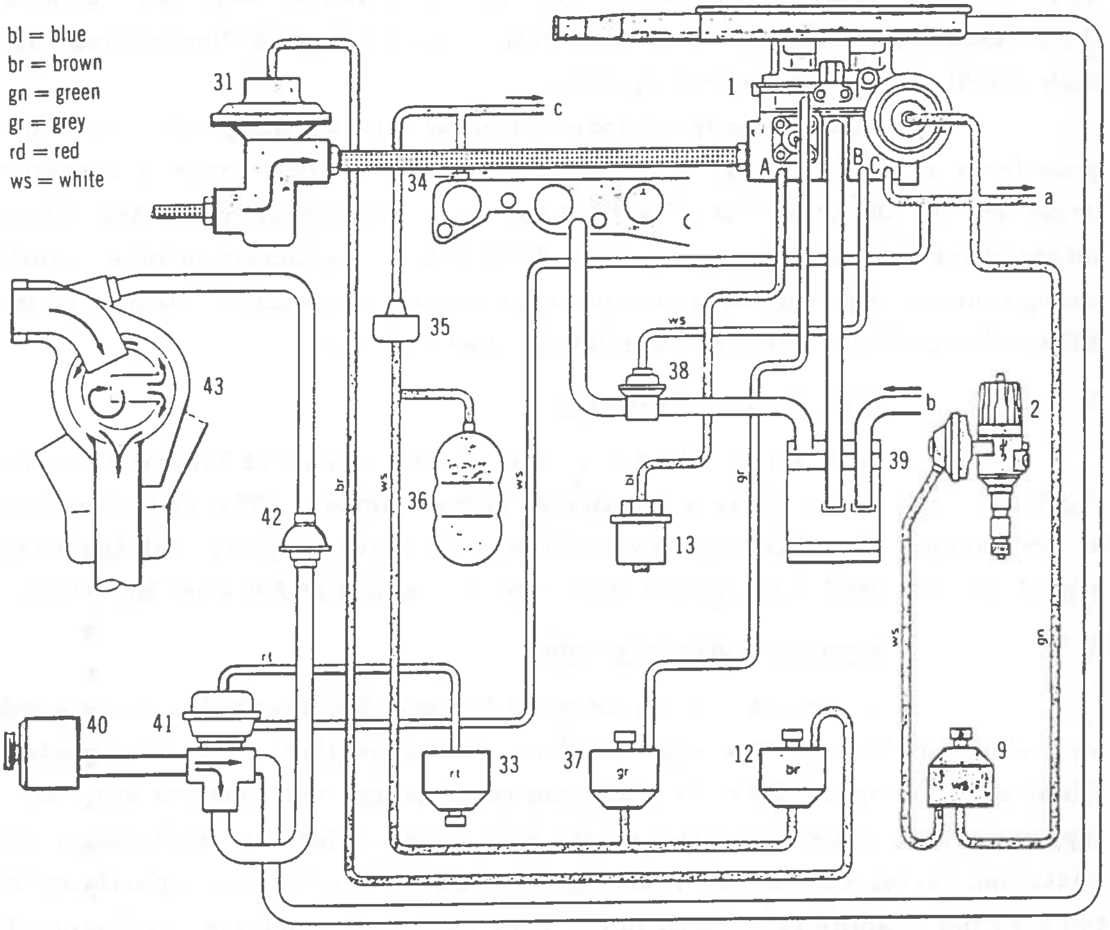
Basic timing and centrifugal and vacuum advance/retard settings for other model years are listed in Table 5-14. Relative to 1972, the combined basic timing and centrifugal advance shows a moderate increase in 1974, combined with a reduction in the vacuum retard. The use of a catalyst in 1975 and 1976 permits additional spark advance, particularly in the low-to-medium speed regime, combined with complete elimination of vacuum retard. The effect of these modifications on fuel economy and emissions is discussed in Section 5.5.10.

5.5.6 Exhaust Gas Recirculation

5.5.6.1 Design Features

All 1974-1976 model engines are equipped with an EGR system which consists of a vacuum-operated EGR control valve, a solenoid-operated switching valve, a vacuum tank, one or two temperature sensors, a vacuum switch, and a speed sensor. In the 1974 system, the flow through the EGR valve is controlled by intake manifold vacuum drawn from the vacuum tank through the switching valve, as shown in Figure 5-13. When energized, the switching valve is open, admitting vacuum to the EGR valve, which opens under these conditions. Conversely, when the switching valve is de-energized, ambient pressure is admitted to the EGR valve, and the valve is closed. The position of the switching valve is controlled by the temperature sensors, the engine speed sensor, and the vacuum switch which closes at high vacuum to interrupt the electrical circuit to the switching valve. EGR is deactivated for oil temperatures below 63°F, cooling water temperatures below 150°F, and engine speeds above 3400 rpm, as well as during idle, deceleration, and WOT operation. The 1974 California system is similar, except that the oil temperature and engine speed sensors have been eliminated.

The EGR system controls have been modified, in 1975, for improved EGR flow and engine load matching. The modifications consist of the addition of carburetor venturi vacuum as a control parameter and the use of a vacuum amplifier. The large diaphragm of the amplifier is connected to venturi vacuum and is balanced by the combined forces generated by a spring and by a small governor diaphragm which is connected to the manifold vacuum.



1 CARBUETOR
2 IGNITION DISTRIBUTOR
9 SWITCH-OVER VALVE, IGNITION
12 SWITCH-OVER VALVE, EGR
13 VACUUM SWITCH
31 EXHAUST GAS RECIRCULATION VALVE
33 SWITCH-OVER VALVE, AIR INJECTION
34 VACUUM CONNECTION, INTAKE MANIFOLD
35 CHECK VALVE
36 VACUUM TANK IN RIGHT FENDER
37 SWITCH-OVER VALVE, FUEL EVAPORATION SYSTEM
38 PURGE VALVE
39 CHARCOAL CANISTER
40 AIR PUMP
41 ANTI-BACKFIRE VALVE
42 CHECK VALVE
43 REACTOR
a VACUUM CONNECTION, FUEL RETURN VALVE
b VACUUM CONNECTION, FUEL VAPORS FROM TANK
c VACUUM CONNECTION, HEATER AND AIR CONDITIONER
A CONNECTION, VACUUM SWITCH
B CONNECTION, EVAPORATOR CONTROL VALVE
C CONNECTION, FUEL RETURN VALVE, ANTI-BACKFIRE VALVE, IGNITION CHANGE-OVER, AND VACUUM GOVERNOR

FIGURE 5-13. EMISSION CONTROL SYSTEM SCHEMATIC: MERCEDES BENZ 167.5-CID ENGINE

The vacuum admitted to the EGR valve via the switching valve is a result of the force balance. The 10:1 surface ratio between the two diaphragms assures high sensitivity of the control system.

EGR is rendered inoperative by the switching valve when the gear lever is not in the drive position. Also, for cooling water temperatures below 150°F, the temperature switch opens, grounding the switching valve and interrupting the vacuum supply to the EGR valve. Reduction in inlet manifold vacuum under high engine load conditions causes progressive closure of the EGR valve until the valve is completely closed at WOT.

5.5.6.2 EGR Valve Calibration

EGR valve calibration data are presented in Figure 5-14, showing EGR mass flow rate as a function of signal vacuum. The EGR flow is zero at low vacuum signal levels (low loads) and increases rapidly with increasing signal vacuum until a maximum flow rate is reached at 200-mm Hg vacuum.

5.5.7 Secondary Air Injection

As an aid in the control of HC and CO, Mercedes-Benz employs secondary air in all 1974-1976 model 167.5-CID engines. The 1974 system, illustrated in Figure 5-13, is of conventional design and consists of a vane-type air pump, pressure relief valve, anti-backfire (or diverter) valve, solenoid switching valve, check valve, and speed switch. In addition, a partially insulated thermal reactor is utilized in the 1974 California vehicles, replacing the conventional exhaust manifold. The capacity of the air pump is 45 cfm at 6000 rpm.

Below 3450 rpm, the switching valve is energized, permitting the flow of secondary air into the exhaust ports of the engine. Conversely, at speeds below 3450 rpm, the speed switch is activated, breaking the electric circuit to the switching valve. As a result, ambient pressure is then supplied to the diaphragm chamber of the anti-backfire valve, closing the valve and rerouting the secondary air back to the air cleaner.

The 1975 and 1976 system is similar to the 1974 configuration, except for the switching valve which is now controlled by oil temperature rather than engine speed. For oil temperatures below 63°F, the switching valve is deactivated and the anti-backfire valve is closed, causing the air flow to be dumped into the air cleaner.

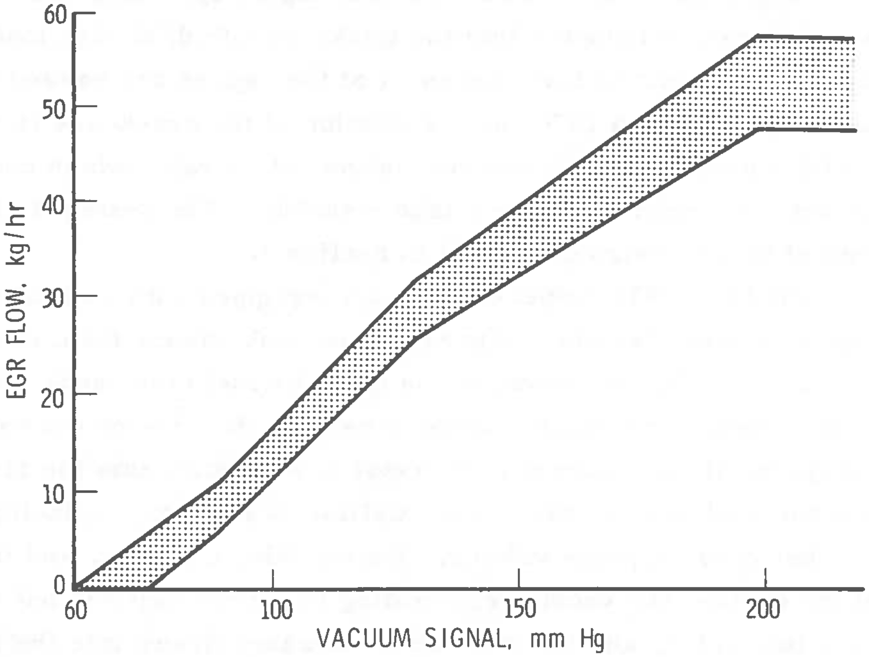


FIGURE 5-14. EGR VALVE CALIBRATION: 1975 AND 1976 MERCEDES BENZ 167.5-CID ENGINE; 49-STATES AND CALIFORNIA CALIBRATION

5.5.8 Catalytic Converter

In 1975 and 1976, the burden of HC and CO control is shifted from the thermal reactor to an oxidation catalyst, which is used in conjunction with the previously discussed secondary air system. The stainless steel catalyst canister contains two monolythic substrates coated with a platinum/palladium mixture, using a total noble metal loading of 0.074 troy oz. The substrates are restrained axially and radially in the canister by means of a wire mesh arrangement.

5.5.9 Crankcase and Evaporative Emission Control

The crankcase emission control system used by Mercedes Benz in 1972 is a simple one, consisting of a hose connection between the valve cover and an oil separator which, in turn, is connected to the air cleaner inlet and to the intake manifold. Under normal engine operating conditions, the crankcase vapors are inducted into the intake manifold; at high loads, the intake manifold vacuum is low, and most of the vapors are passed through the air cleaner. In 1975 and 1976, air ventilation of the crankcase is used in conjunction with a positive crankcase ventilation (PCV) valve which controls the flow of crankcase vapors into the intake manifold. The system is functionally identical to the design described in Section 3.

All 1972-1976 model engines are equipped with an evaporative emission control system designed to prevent fuel tank vapors from entering the atmosphere. In 1972, the crankcase is used for fuel tank vapor storage after engine shutdown. The same system is used in the 1974 model 49-states vehicles, except for the addition of carburetor bowl venting into the air cleaner. In 1974, a carbon canister is added to the California system, replacing the crankcase as fuel vapor storage volume. During idle, coasting, and full-load operation of the engine, the vacuum controlling the purge valve is not large enough to open this valve, and the fuel vapors are then drawn into the intake manifold through a small 0.04-inch-diameter bypass orifice. Conversely, at part load the purge valve opens providing the additional flow area required for regeneration of the carbon granules in the canister. A detailed description of the functional characteristics of evaporative emission control systems is presented in Section 3.

5.5.10 Fuel Economy and Emissions

Table 5-14 lists fuel economy and emission data for the 1974-1976 certification vehicles (Refs. 5-8 through 5-11 and 5-13), while Figure 5-15 shows the normalized and corrected city fuel economy data of these vehicles, adjusted for variations in inertia weight and rear axle ratio. The normalization method is described in Section 3. Also shown in Figure 5-15 is the normalized fuel economy of the 1973 vehicles (Ref. 5-20).

The city fuel economy of the 1974 California vehicles is about 22 percent lower than for the 49-states vehicles and is accompanied by substantial reductions in HC, CO, and NO_x. The observed fuel economy degradation is primarily attributed to the richer air/fuel mixture settings used in the California vehicles for the purpose of maintaining sufficiently high temperatures in the thermal reactor for effective HC and CO control. While the richer mixtures resulted in some reduction in NO_x, the California vehicles require more EGR than the 49-states vehicles to meet the more stringent 2.0 g/mi California NO_x standard, at the expense of some additional loss in fuel economy. Other factors that might contribute to the observed fuel economy differences include test-to-test and vehicle-to-vehicle variabilities.

Mercedes Benz uses identical engine calibrations for all 1975 and 1976 model 49-states and California vehicles except for the use of slightly leaner air/fuel mixtures in 1976. While this approach reduces development and certification program costs, it is considered to be undesirable from an energy conservation point of view because of inherent fuel economy penalties associated with the more stringent California standards. Considering the leaner air/fuel mixtures, the advanced spark timing, and the elimination of spark retard in 1975 relative to 1974, the observed improvement in fuel economy is unusually small. Again, test-to-test and vehicle-to-vehicle variabilities are factors potentially contributing to the apparent discrepancy.

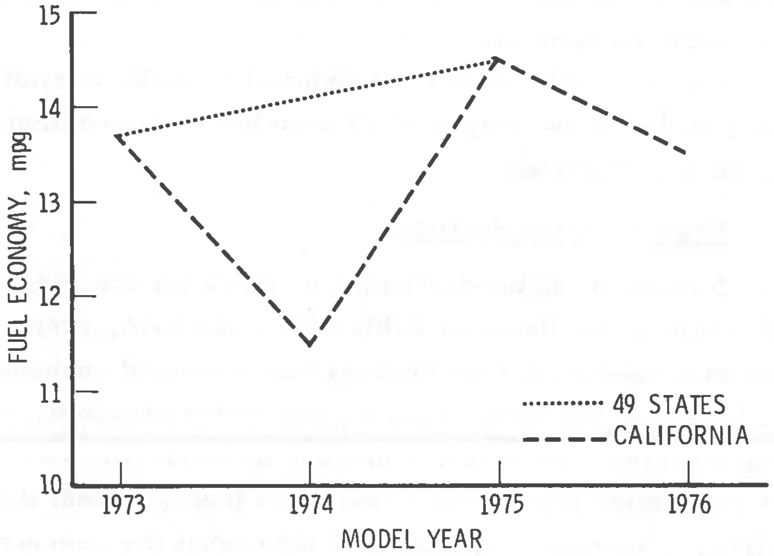


FIGURE 5-15. NORMALIZED AVERAGE CITY FUEL ECONOMY: MERCEDES BENZ 167.5-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

The observed fuel economy difference between 1975 and 1976 is not significant in view of the small data sample available for the two model years.

The marked HC and CO reductions realized in 1975 and 1976 relative to 1974 are directly related to the use of an oxidation catalyst in 1975 and 1976. The fuel economy advantage associated with catalytic emission control relative to control by means of a thermal reactor is illustrated by comparing the 1974 California vehicles and the 1975 and 1976 vehicles. As indicated in Table 5-14, the city fuel economy in 1975 is about 26 percent higher than in 1974. This improvement is directly attributed to the much leaner air/fuel ratios and higher spark advance settings used in 1975.

5.6 NISSAN

5.6.1 Engine/Vehicle Configurations

The Nissan engines selected for this study include the 119.1-CID and 85.2-CID designs. The 119.1-CID engine was introduced in 1974 for use in the Datsun 610 and 710 series vehicles. These vehicles, which are offered either with automatic or manual transmission, fall in the 2750-3000 pound inertia weight categories.

The 85.2-CID engine, introduced in 1975, is similar in design and is used primarily in the Datsun B210 vehicles in conjunction with an automatic or manual transmission.

5.6.2 Engine Design Features

Important engine design parameters for the Nissan 119.1-CID and 85.2-CID engines are listed in Tables 5-15 and 5-16, respectively. As indicated, the basic design of both engines has remained unchanged since their introduction, including the wedge shaped combustion chamber, compression ratio, and valve timing. However, a number of emission control system modifications and calibration adjustments have been incorporated; these are addressed in the following sections. It should be noted that the combustion chamber surface-to-volume ratio of the 85.2-CID engine is higher than for most other engines considered in this study. While high surface-to-volume ratios are generally associated with high HC emissions, the emissions of the vehicles using this engine are comparable to other equivalent engine/vehicle configurations, as discussed in Section 5.6.4.8. However, the 85.2-CID engine

TABLE 5-15. ENGINE SPECIFICATIONS: NISSAN 119.1-CID ENGINE

Engine Parameter	Model Year					
	1976 49 States	1976 California	1975 49 States	1975 California	1974 49 States	1974 California
No. of Cylinders	4		4		4	
Bore, in.	3.35		3.35		3.35	
Stroke, in.	3.39		3.39		3.39	
Displacement, cu in.	119.1		119.1		119.1	
Surface/Volume, 1/in.	6.82		6.82		6.82	
Compression Ratio	8.5		8.5		8.5	
Cylinder Head Type	OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	110 at 5600	107 at 5600	110 at 5600	107 at 5600	110 at 5600	
Torque, ft-lb, at Engine Speed, rpm	112 at 3600		112 at 3600		112 at 3600	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.65		1.65		1.65	
Intake Valve Lift, in.	0.41		0.41		0.41	
Exhaust Valve Diameter, in.	1.38		1.38		1.38	
Exhaust Valve Lift, in.	0.41		0.41		0.41	
Intake Valve Opens, deg BTC	16		16		16	
Intake Valve Closes, deg ABC	52		52		52	
Intake Valve Duration, deg	248		248		248	
Exhaust Valve Opens, deg BBC	54		54		54	
Exhaust Valve Closes, deg ATC	14		14		14	
Exhaust Valve Duration, deg	248		248		248	
Valve Overlap, deg	30		30		30	
Distributor Type	Breaker point	Transistorized	Breaker point	Transistorized	Breaker point	
Basic Ignition Advance, deg BTC	12		12		12	
Idle Speed, rpm[a]	650 (A) 750 (M)		650 (A) 750 (M)		650 (A) 750 (M)	
Fast Idle Speed, rpm[a]	2400 (A) 2000 (M)		2400 (A) 2000 (M)		2400 (A) 2000 (M)	
Fuel System Type	2-V downdraft		2-V downdraft		2-V downdraft	
Enrichment Method	Power valve		Power valve		Power valve	
Choke Type	Automatic electric assist		Automatic electric assist		Automatic electric assist	
Carburetor Venturi Diameter, in.	0.945 (1V) 1.22 (2V)		0.945 (1V) 1.22 (2V)		0.905 (1V) 1.11 (2V)	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	200 at 2.5		200 at 2.5		200 at 2.5	
Emission Control Systems	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV	AIR EGR EVAP PCV	
Emission Control Devices	Deceleration device Spark delay Spark retard		Deceleration device Spark delay Spark retard		Deceleration device	

[a] A = automatic transmission; M = manual transmission

TABLE 5-16. ENGINE SPECIFICATIONS: NISSAN 85.2-CID ENGINE

Engine Parameter	Model Year			
	1976		1975	
	49 States	California	49 States	California
No. of Cylinders	4		4	
Bore, in.	2.99		2.99	
Stroke, in.	3.03		3.03	
Displacement, cu in.	85.2		85.2	
Surface/Volume, 1/in.	8.97		8.97	
Compression Ratio	8.5		8.5	
Cylinder Head Type	OHC		OHC	
Advertised HP at Engine Speed, rpm	80[a] at 6000	78[a] at 6000	80[a] at 6000	78[a] at 6000
Torque, ft-lb, at Engine Speed, rpm	83 at 3600		83 at 3600	
Exhaust System Type	Single		Single	
Combustion Chamber Configuration	Wedge		Wedge	
Intake Valve Diameter, in.	1.46		1.46	
Intake Valve Lift, in.	0.32		0.32	
Exhaust Valve Diameter, in.	1.18		1.18	
Exhaust Valve Lift, in.	0.33		0.33	
Intake Valve Opens, deg BTC	14		14	
Intake Valve Closes, deg ABC	54		54	
Intake Valve Duration, deg	248		248	
Exhaust Valve Opens, deg BBC	56		56	
Exhaust Valve Closes, deg ATC	20		20	
Exhaust Valve Duration, deg	256		256	
Valve Overlap, deg	34		34	
Distributor Type	Breaker point	Transistorized	Breaker point	Transistorized
Basic Ignition Advance, deg BTC[b]	10	10	10	8 (A) 10 (M)
Idle Speed, rpm[b]	650 (A) 700 (M)		650 (A) 700 (M)	
Fast Idle Speed, rpm[b]	2800 (A) 2550 (M)		-	
Fuel System Type	2-V downdraft		2-V downdraft	
Fuel Metering Method	-		-	
Enrichment Method	Power valve		Power valve	
Choke Type	Automatic electric assist		Automatic electric assist	
Carburetor Venturi Diameter, in.	0.91 (1V) 1.06 (2V)		0.91 (1V) 1.06 (2V)	
Carburetor Maximum Air Flow, cfm, at Vacuum, in. Hg	114 at 2.0		114 at 2.0	
Emission Control Systems	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV
Emission Control Devices	Deceleration device Spark delay[c] Spark retard[d]		Deceleration device Spark delay[c] Spark retard[d]	

[a] Gross ratings

[b] A = automatic transmission; M = manual transmission

[c] Automatic only

[d] Manual only

equipped vehicles incorporate secondary air (49-states) or secondary air plus a catalyst (California), while the 119.1-CID engine which has a lower surface-to-volume ratio meets the standards without these devices. (Refs. 5-49 through 5-53).

5.6.3 Nissan 119.1-CID Engine

5.6.3.1 Intake System

A heated intake air system is provided to improve the fuel vaporization and engine warmup characteristics. This permits the application of leaner carburetor calibrations, resulting in lower HC and CO emissions during the cold start phase of the driving cycle. In this system, air is drawn into the air cleaner either through the snorkel or through the exhaust manifold heated air passage. An air control valve, located in the air intake pipe, is operated by inlet manifold vacuum through a temperature sensor which modulates the admission of hot air to maintain an inlet air temperature of approximately 110°F. However, at full throttle (low vacuum), the hot air valve remains closed regardless of temperature to provide maximum engine power.

As an additional cold start HC control measure, the 1975 and 1976 engines are equipped with a quick heat intake manifold and valve arrangement which accelerates fuel vaporization and improves cold start vehicle driveability and fuel economy. The valve, which is located in the intake passage, is controlled by a bimetallic strip, forcing the fuel/air mixture around the stove during a cold start. After the engine is warmed up, the valve opens providing direct entry of the mixture into the cylinders.

5.6.3.2 Carburetor

5.6.3.2.1 Design Features

The 119.1-CID engine is equipped with a Zenith-Stromberg type carburetor manufactured by Hitachi. The carburetor is equipped with primary and secondary fuel jets, an accelerator pump, and a power valve providing fuel enrichment at full load and during acceleration. The power valve is controlled by a spring-loaded piston subjected to inlet manifold vacuum. At low vacuum levels (acceleration or full throttle operation), the spring actuates the piston, which opens the valve to admit fuel through a calibrated orifice.

All engines are equipped with an automatic, electrically heated choke. The choke heater has two positions: high current for fast heating to reduce the period of rich mixture operation, when the air temperature is above 34°F and the coolant temperature is below 151°F, and low current for slow heating for air temperatures below 55°F and coolant temperatures above 163°F. The choke has a fast idle cam which limits throttle closure when the engine is cold. An anti-dieseling solenoid valve is used to shut off the supply of fuel to the carburetor when the ignition key is turned off.

All 1975 and 1976 engines as well as the 1974 engines with manual transmission incorporate a boost-controlled deceleration valve (BCDV) designed to reduce HC during vehicle deceleration. The BCDV is an integral part of the carburetor, supplying additional air/fuel mixture from a separate metering system. When low manifold vacuum is detected during deceleration, the vacuum-operated control valve opens, admitting the additional mixture into the manifold to maintain a predetermined manifold vacuum level (BCDV operating vacuum, 20.87-in. Hg). The system is deactivated at speeds below 10 mph (manual transmission) or at the N and P shift positions (automatic transmission) by means of a solenoid, which admits ambient air into the vacuum-activated control valve cavity. The 1974 engines operating with automatic transmission and all 1975 and 1976 engines are equipped with a spring loaded dashpot which provides a high idle speed setting during periods of rapid deceleration to prevent engine stalling.

The 1975 and 1976 model 49-states engines incorporate an idle compensator which supplies a small amount of additional air into the intake manifold to correct the air/fuel ratio and to improve engine idling under extremely hot conditions. This device consists of two bimetallic valves, one opening at air temperatures between 140 and 158°F and the other at air temperatures between 158 and 194°F. To compensate for the reduction in air density at high altitude and the associated mixture enrichment, an altitude compensator is used in all 1975 and 1976 model California vehicles. This device is connected to the carburetor mixing passages through a set of rubber hoses. A bellows located in the compensator expands with increasing altitude, and the lever attached to the bellows moves the tapered needle valve of the compensator. This increases the area of the air passage allowing a larger volume of air to enter the carburetor, hence maintaining a nearly constant air/fuel ratio.

5.6.3.2.2 Carburetor Calibration

Typical Nissan carburetor calibration data, exemplified by the 1976 model 49-states settings for use with automatic and manual transmissions are presented in Figure 5-16, showing the fuel/air ratio for part throttle and WOT operation as a function of air flow through the venturi. Also shown in this figure are the corresponding intake vacuum distributions. As indicated, the part-load mixture is rapidly leaned out in the low flow regime, followed by a nearly constant mixture ratio over a wide range of flow rates and enrichment at high flows. At WOT, the mixture is further enriched to provide full engine power.

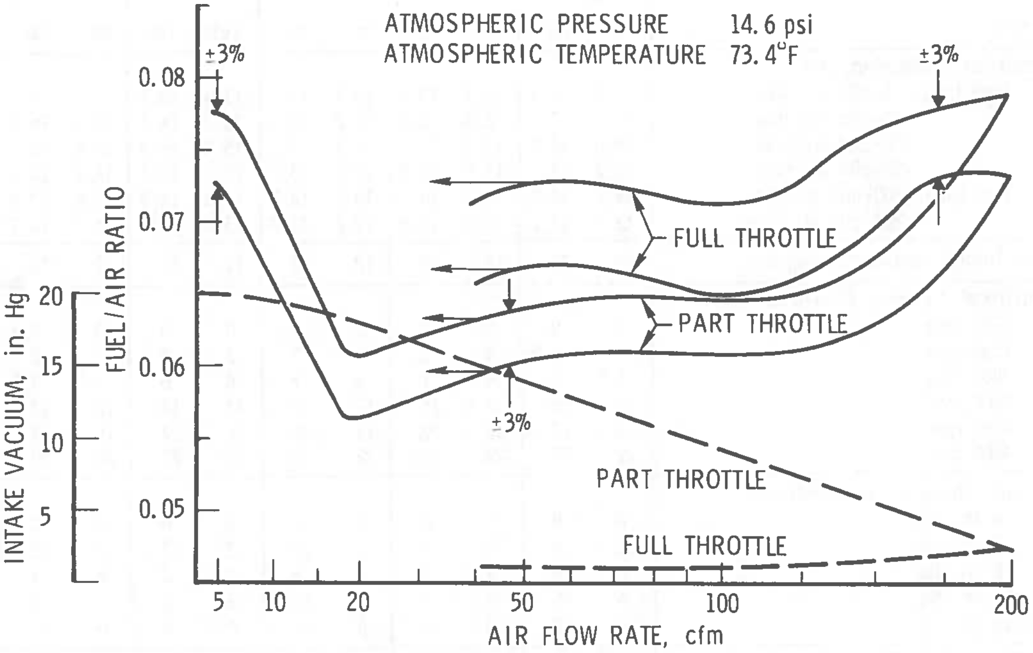


FIGURE 5-16. CARBURETOR FLOW CURVE: 1976 NISSAN 119.1-CID ENGINE WITH MANUAL OR AUTOMATIC TRANSMISSION; 49-STATES CALIBRATION

Carburetor calibration data for other model years and emission levels are presented in Table 5-17, showing the nominal air/fuel ratio at

TABLE 5-17. CERTIFICATION CALIBRATION DATA: NISSAN 119.1-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard									
	1976 49 States		1976 California		1975 49 States		1975 California		1974 California^{a}	
Vehicle Model	710	710	710	710	610	-	-	-	-	-
Transmission Type	A	M	A	M	A	M	A	M	A	M
Inertia Weight, lb	2750	2750	3000	2750	3000	2750	3000	2750	2750	2750
Rear Axle Ratio	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.89	3.70
Catalyst	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Carburetor Calibration, A/F										
Part Load: 5-cfm air flow	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	-	-
20-cfm air flow	17.2	17.2	16.4	16.4	17.2	17.2	16.7	16.7	16.8	16.8
100-cfm air flow	16.0	16.0	15.3	15.3	15.5	15.5	15.4	15.4	16.8	16.8
200-cfm air flow	13.2	13.2	13.0	13.0	13.7	13.7	13.7	13.7	14.2	14.2
Full Load: 100-cfm air flow	14.7	14.7	14.5	14.5	14.9	14.9	14.8	14.8	13.8	13.8
200-cfm air flow	13.2	13.2	13.0	13.0	13.7	13.7	13.7	13.7	14.2	14.2
Basic Timing, crankshaft deg BTC	12	12	12	12	12	12	12	12	12	12
Centrifugal Advance, crankshaft deg										
1000 rpm	0	0	0	0	0	0	0	0	0	0
1500 rpm	3	2.5	3	2	2	2	3	2	2	2
2000 rpm	5.5	6	6	7	6	7	6	6	5.5	5.5
3000 rpm	12	15	12.5	15	12	15	14	14	12	12
4000 rpm	18	22	18	22	18	22	22	22	18	18
4800 rpm	22	22	22	22	22	22	22	22	20	20
Vacuum Advance, crankshaft deg										
6 in. Hg	0	0	0	0	0	0	0	0	0	0
7 in. Hg	2.5	4	2	2	2	4	2	2	2	2
8 in. Hg	4	6	4	4	4	6	4	4	4	4
10 in. Hg	6	10	6	6	6	10	6	6	6	6
12 in. Hg	6	10	6	6	6	10	6	6	6	6
EGR Valve Calibration										
Signal Vacuum To Open, in. Hg	2.8	2.8	2.0	2.0	2.8	2.8	2.0	2.0	2.0	2.0
Flow Rate, cfm: 2.5-in. Hg	0	0	3.5	2.0	0	0	3.4	2.6	3.4	2.6
3-in. Hg	1	0.6	6.4	3.4	1	0.6	6.7	4.3	6.7	4.3
3.5-in. Hg	2.5	1.4	8.8	4.4	2.5	1.4	9.0	6.0	9.0	6.0
4-in. Hg	3.5	1.8	10.6	5.4	3.6	1.8	10.6	7.0	10.6	7.0
5-in. Hg	3.5	2.5	10.6	5.4	3.6	2.5	10.6	7.0	10.6	7.0
Fuel Economy, mpg										
City	23	23	23	22	20	22	18	21	19.8^{b}	20.6^{b}
Highway	29	33	28	23	25	33	23	29	-	-
Exhaust Emissions, g/m										
HC	1.2	1.2	0.4	0.6	1.2	1.0	0.3	0.4	1.7^{b}	2.3^{b}
CO	13	11	4	4	10	8	5	3	23^{b}	21^{b}
NO_x	1.8	1.9	1.5	1.4	2.0	2.0	1.6	1.5	1.3^{b}	1.2^{b}

[a] Only California vehicles certified.

[b] 1972 FTP.

discrete part-load and full-load air flow settings. Relative to 1974, the air/fuel ratio modifications implemented in 1975 and 1976 are small, varying between about 5 percent for an air flow rate of 20 cfm to about 10 percent at 100 cfm. As an aid in the control of HC and CO, the calibration tolerance has been reduced in 1976 to ± 3 percent from the ±7 percent level used in previous years.

5.6.3.3 Ignition System

5.6.3.3.1 Design Features

As shown in Table 5-15, a conventional breaker-point ignition system is employed in all 1974 model year engines, as well as in the 1975 and 1976 model 49-states vehicles. Conversely, the 1975 and 1976 California engines are equipped with a transistorized ignition system using an inductive distributor rotor head in place of the mechanical breaker points employed in conventional units. Both distributors use conventional centrifugal and vacuum advance mechanisms.

5.6.3.3.2 Spark Timing Control Devices

For HC and CO emission control purposes, the 1975 and 1976 model year engines are equipped with ignition retard and ignition advance systems. The ignition retard system, which is used only in conjunction with manual transmission, retards the spark advance by means of a vacuum switching valve. Under all engine operating conditions, except in neutral or top gear, the switching valve is actuated by a solenoid control valve which then interrupts the vacuum supply to the distributor vacuum chamber, providing spark timing retard.

The spark delay system is used only in automatic transmission installations. It consists of a one-way umbrella-type valve and a number of orifices installed in the vacuum line between the carburetor vacuum port and the distributor. The system is designed to delay vacuum advance during rapid acceleration and to eliminate vacuum advance during deceleration.

5.6.3.3.3 Spark Advance Schedules

Basic ignition timing, as well as centrifugal and vacuum advance schedules, for the 119.1-CID engine are listed in Table 5-17. As indicated, the centrifugal advance for speeds below 2000 rpm and above 4800 rpm remains nearly constant between 1974 and 1976, independent of transmission type and emission regulations. Conversely, in the mid-speed regime, the centrifugal advance of the vehicles with manual transmission is about 4 crankshaft deg higher than for automatic transmission equipped vehicles. Unlike most other manufacturers, Nissan uses identical centrifugal advance schedules for both 49-states and California calibrations.

With regard to vacuum advance, Table 5-17 shows no change between 1974 and 1976, except for the 1975 and 1976 model 49-states vehicles with manual transmission. The vacuum advance of these vehicles at vacuum settings of 10-in. Hg and above is about 4 crankshaft deg higher than for all other calibrations.

For emission control purposes, Nissan has reduced the calibration tolerance band for the vacuum advance from about ±2 crankshaft deg at high vacuum levels and about ±3 deg at low vacuum in 1974 and 1975 to about ±1 and ±1.5 crankshaft deg, respectively, in 1976. In addition, the tolerance band of the centrifugal advance schedule has been reduced from about ±2.5 crankshaft deg in 1974 to about ±1 crankshaft deg in 1976.

5.6.3.4 Exhaust Gas Recirculation

5.6.3.4.1 Design Features

To facilitate NO_x control, all 119.1-CID engines are equipped with EGR. The system used by Nissan in 1974 consists of an EGR control valve, installed on the intake manifold, which controls the flow rate of the recirculated exhaust gases as a function of carburetor port vacuum. EGR is inoperative at idle and at full throttle. To assure good vehicle driveability, EGR is also inoperative at low engine temperatures.

The vacuum signal which acts on the valve diaphragm serves as the primary flow control parameter. The movement of the diaphragm is transmitted to the tapered EGR valve, which modulates the EGR flow in accordance with a predetermined schedule. In addition, an auxiliary control system is employed, which is designed to improve engine idle and vehicle driveability at low engine temperatures and to preserve the full power output capability of the engine at WOT. This system is composed of a coolant temperature sensor and a three-way solenoid valve. For engine coolant temperatures below 97^oF, the solenoid valve is energized, shutting off the vacuum line passage to the diaphragm. As a result, ambient pressure is admitted to the diaphragm closing the EGR valve. Above the control temperature, the solenoid is de-energized, rendering the EGR system inoperative. The vacuum port in the carburetor is positioned in such a manner that near ambient pressure is admitted to the EGR valve diaphragm chamber under idle and WOT operation of the engine.

The same basic EGR system is employed in 1975 and 1976. However, in 1975 the coolant temperature control limit for the 49-states and California vehicles is increased to 140°F. The 1976 control limits for these installations are 135-145°F for increasing coolant temperature and 104-135°F for declining temperature. In addition to these control limits, the EGR system used in the 1975 and 1976 model 49-states vehicles with manual transmission is rendered inoperative in neutral and top gear by means of a vacuum switching valve which replaces the vacuum supply to the EGR diaphragm with ambient pressure. Conversely, the 1975 and 1976 California vehicles with manual transmission incorporate a vaccum and coolant temperature controlled EGR system without the gear control feature.

To assure proper maintenance of the EGR system, a warning light appears on the instrument panel of the 49-states vehicles at 12,500 mile intervals. This light stays on until reset at the time of system maintenance.

5.6.3.4.2 EGR Valve Calibration

Typical EGR valve calibration data, exemplified by the 1975 and 1976 California vehicles with automatic transmission, are presented in Figure 5-17, showing the air flow through the valve as a function of carburetor port vacuum. Flow through the valve commences at about 2-in. Hg signal vacuum and increases rapidly with increasing vacuum until the saturation flow of 10.5 cfm is reached at about 4-in. Hg.

Calibration data for other 1975 and 1976 model year vehicles are listed in Table 5-17, showing the valve opening vacuum and the nominal flow rates through the EGR valve at a number of discrete vacuum signal settings. As indicated, the same EGR rates are used at the two calibration levels (49-states and California) in 1975 and 1976, except for the California vehicles with manual transmission, which use more EGR in 1975 than in 1976. As expected, the EGR flow rates of the California vehicles are substantially higher than for

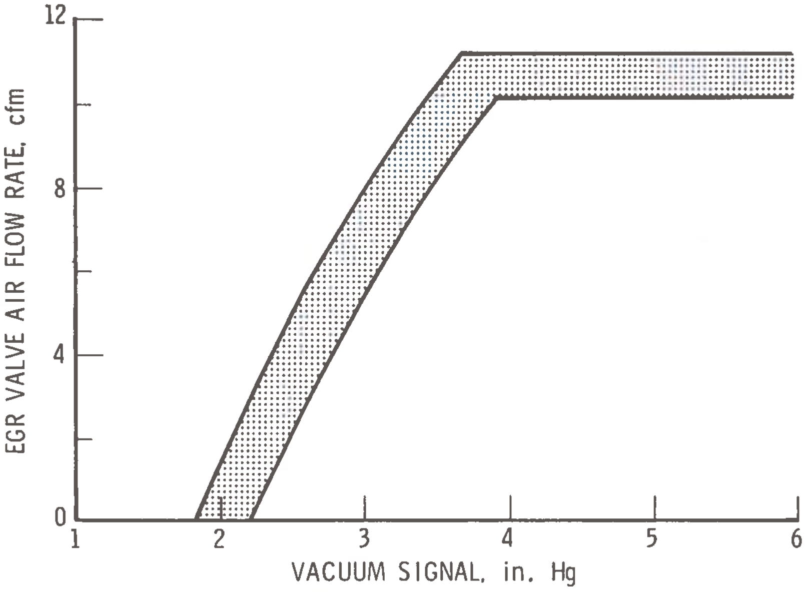


FIGURE 5-17. EGR VALVE CALIBRATION: 1975 and 1976 NISSAN 119.1-CID ENGINE WITH AUTOMATIC TRANSMISSION; CALIFORNIA CALIBRATION

the 49-states vehicles, reflecting the more stringent California NO_x standard. While the basic EGR system has remained unchanged since 1974, closer flow calibration tolerances are used in 1976 relative to 1974 and 1975, particularly in the low EGR flow regime. For example, in the case of the 49-states vehicles with automatic transmission, the flow tolerances have been reduced from ±0.32 cfm at high flow rates and ±0.75 cfm at low flow rates in 1975 to about ±0.26 cfm in 1976. Similar improvements have been implemented for the manual transmission equipped vehicles. While the flow tolerances of the California vehicles are higher than for the 49-states vehicles (± 0.5/ ±1.5 cfm for automatic transmission and ±0.6/ ±1.0 cfm for manual transmission in 1975), similar reductions generally have been achieved in 1976 (±0.64/ ±0.44 cfm for automatic transmission and ±0.32/0.32 cfm for manual transmission.

5.6.3.5 Secondary Air Injection

All 119.1-CID engines are equipped with a secondary air injection system for HC and CO emission control. Like other systems, the Nissan unit consists of a conventional vane-type air pump, drawing air from the air cleaner and injecting it into each of the four exhaust valve ports. Other system components include a pressure relief valve, check valve, and anti-backfire valve. The air pump pulley ratio is 0.9:1, and the capacity of the pump is about 11 cfm at a pump speed of 3000 rpm.

In addition to the basic components, an air control valve (ACV) and an emergency air relief valve (EARV) are used in the 1975 and 1976 California systems. The ACV controls the quantity of secondary air admitted into the exhaust as a function of engine speed and load, using a diaphragm-operated valve. The operation of this valve is controlled by intake vacuum and pump discharge pressure. At part load and high engine speeds, some of the air is discharged back into the air filter to prevent overheating of the catalytic converter. Additional catalyst protection is provided by the EARV, which is controlled by manifold vacuum. When the valve solenoid is energized, vacuum admitted to the EARV opens this valve and releases all secondary air to atmosphere. The solenoid is energized when the catalyst temperature reaches 1560°F.

5.6.3.6 Catalytic Converter

To assist in the control of HC and CO, all California vehicles incorporate a catalytic converter, installed in the exhaust system about half way between the exhaust manifold and muffler. Identical units are used in 1975 and 1976. The catalyst system incorporates a protection device consisting of a catalyst temperature sensor, a floorboard temperature sensor, a switching module, a warning light with holding relay, and the previously described EARV. The warning light is activated for catalyst or flow temperatures of about 2000 and 2400°F, respectively.

5.6.3.7 Crankcase and Evaporative Emission Control

All 119.1-CID engines are equipped with conventional and identical closed crankcase ventilation (CCV) systems of the type described in Section 3.

The evaporative emission control system used in 1974 consists of a sealed fuel tank cap, a vapor-liquid separator, a vapor vent line from the fuel tank to the engine crankcase, and a three-way flow valve. The fuel vapors which enter the crankcase through the flow valve are scavenged into the intake manifold through the PCV valve. After the engine is turned off, the vapors are stored in the crankcase. In 1976, the crankcase storage system is replaced by a conventional carbon canister and diaphragm-type vacuum-actuated purge valve arrangement of the type described in Section 3.

5.6.3.8 Fuel Economy and Emissions

Fuel economy and emissions data for selected certification vehicles are listed in Table 5-17, (Refs. 5-8 through 5-10). The city fuel economy of these vehicles and of all other certification vehicles not listed in this table has been normalized in accordance with the procedure outlined in Section 3. As indicated in Figure 5-18, the normalized average city fuel economy shows a declining trend between 1974 and 1975, particularly for the California vehicles with automatic transmission, followed by significant improvements in 1976.

Except for the 1976 California vehicles with automatic transmission the 1975 and 1976 California vehicles show lower fuel economy than the corresponding 49-states vehicles, accompanied by lower HC, CO and NO_x emissions (Figure 5-19). The observed variations are primarily attributed to the higher EGR flow rates and the use of a catalyst in the California vehicles in order to meet the more stringent California emissions regulations. Similar trends are obtained for the highway fuel economy.

In general, the observed fuel economy trends of the 49-states and California vehicles between 1974 and 1976 are difficult to explain on the basis of the relatively small variations in air/fuel ratio, spark timing, and emission control system design. It appears, however, that the use of smaller carburetor, distributor, and EGR valve calibration tolerances, combined with better system optimization, might be responsible for at least part of the fuel economy gains in 1976. Other factors not investigated in this study could influence the observed trends, including potential improvements in transmission efficiency as well as normal test-to-test and vehicle-to-vehicle variabilities.

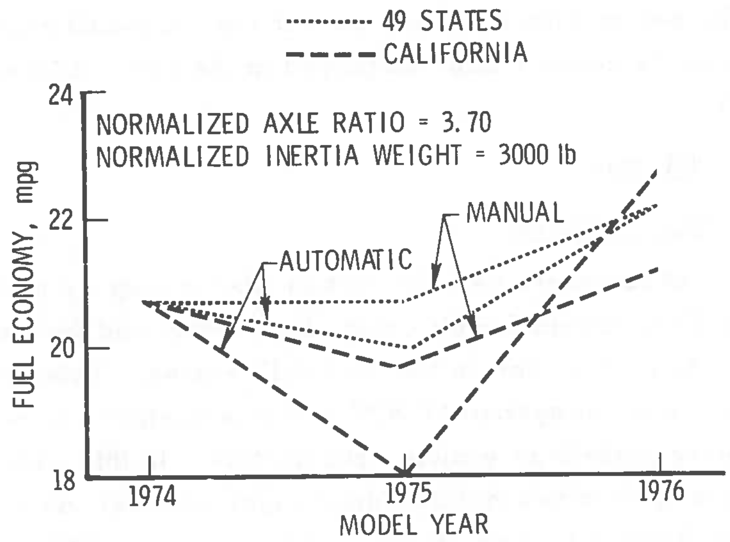


FIGURE 5-18. NORMALIZED AVERAGE CITY FUEL ECONOMY: NISSAN 119.1-CID ENGINE

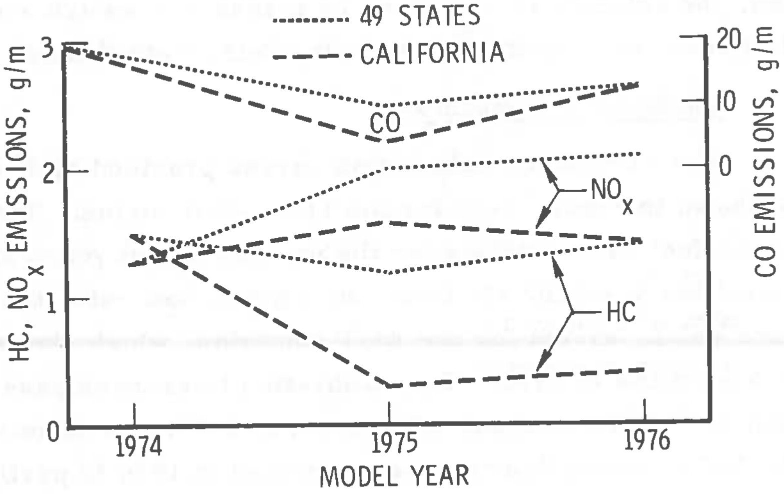


FIGURE 5-19. AVERAGE EXHAUST EMISSIONS: NISSAN 119.1-CID ENGINE WITH AUTOMATIC TRANSMISSION; 1975 FTP

5.6.4 Nissan 85.2-CID Engine

5.6.4.1 Intake System

The heated intake system used in the 85.2-CID engine is functionally identical to the configuration employed in the 119.1-CID engine (Section 5.6.3.1).

5.6.4.2 Carburetor

5.6.4.2.1 Design Features

The carburetors used in the two Nissan engines considered in this study are similar, except for different size venturi and fuel jets and the use of a deceleration control unit in the 85.2-CID engine. This device consists of a throttle opener control system (TOCS) which is designed to reduce HC and CO emissions during periods of vehicle deceleration. In this case, intake manifold vacuum is applied to the TOCS diaphragm chamber via a vacuum valve, causing the throttle to open slightly. As a result, additional air is admitted, preventing the formation of excessively lean air/fuel mixtures. In manual transmission vehicles, TOCS is rendered inoperative for vehicle speeds below 10 mph, by energizing the solenoid valve and applying ambient pressure to the diaphragm chamber. Conversely, in vehicles with automatic transmission, the solenoid is energized by means of a switch which is activated when the shift lever is in neutral or in park (Refs. 5-49 through 5-52).

5.6.4.2.2 Carburetor Calibration

The carburetor calibration curves provided by Nissan are similar to those shown in Figure 5-16 for the 119.1-CID engine. Table 5-18 lists the nominal air/fuel ratio settings for the various model years and calibration levels as a function of engine air flow. At a given flow rate, the air/fuel ratio variations are small, except for the WOT condition, which shows a moderate air/fuel ratio increase in 1976. The calibration tolerances have been reduced to ±3 percent in 1976 from about ±7 percent in 1975. As discussed in Section 5.6.4.8, the fuel economy improvement realized in 1976 is partly attributed to the use of tighter tolerances.

TABLE 5-18. CERTIFICATION CALIBRATION DATA: NISSAN 85.2-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard												
	1976 49 States				1976 California					1975 49 States		1975 California	
Transmission Type	A	M4	M4	M5	A	A	M4	M4	M5	A	M4	A	M4
Inertia Weight, lb	2250	2250	2250	2250	2250	2250	2250	2250	2250	2500	2250	2500	2250
Rear Axle Ratio	3.89	3.89	3.70	3.70	3.89	3.89	3.70	3.89	3.70	3.89	3.89	3.89	3.89
Catalyst	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Carburetor Calibration, A/F													
Part Load: 5-cfm air flow	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
20-cfm air flow	17.2	17.2	17.2	17.2	16.8	16.8	16.8	16.8	16.8	17.4	17.4	17.0	17.0
50-cfm air flow	16.5	16.5	16.5	16.5	16.2	16.2	16.2	16.2	16.2	16.5	16.5	16.1	16.1
110-cfm air flow	14.7	14.7	14.7	14.7	14.6	14.6	14.6	14.6	14.6	13.8	13.8	13.8	13.8
Full Load: 50-cfm air flow	15.3	15.3	15.3	15.3	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.0	15.0
110-cfm air flow	14.7	14.7	14.7	14.7	14.6	14.6	14.6	14.6	14.6	13.8	13.8	13.8	13.8
Basic Timing, crankshaft deg BTC	8	8	8	8	8	8	8	8	8	8	8	10	10
Centrifugal Advance, crankshaft deg													
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	4	3.5	4
2000 rpm	8	7.5	7.5	7.5	8	8	7.5	7.5	7.5	8	8	8	8
3000 rpm	16.5	15	15	15	16.5	16.5	15	15	15	16.5	17	16.5	17
4000 rpm	25.5	23.5	23.5	23.5	25.5	25.5	23.5	23.5	23.5	25.5	25	25.5	25
4800 rpm	28	28	28	28	28	28	28	28	28	27	27	27	27
Vacuum Advance, crankshaft deg													
5 in. Hg	0	4	4	4	0	0	4	4	4	0	0	0	0
6 in. Hg	0	7	7	7	0	0	7	7	7	0	8	0	8
7 in. Hg	0	10	10	10	0	0	10	10	10	1	12	1	12
8 in. Hg	4	13	13	13	4	4	13	13	13	4	15	4	15
10 in. Hg	9	18	18	18	9	9	18	18	18	9.5	18	9.5	18
12 in. Hg	13	18	18	18	13	13	18	18	18	12.5	18	12.5	18
EGR Valve Calibration													
Signal Vacuum To Open, in. Hg	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Flow Rate, cfm: 3-in. Hg	0.6	0.6	0.6	0.6	1.5	1.5	1	1	1	0.6	0.6	1.4	0.8
3.5-in. Hg	1.3	1.3	1.3	1.3	4	4	2.5	2.5	2.5	1.4	1.4	3.8	2.5
4-in. Hg	1.8	1.8	1.8	1.8	5.3	5.3	3.5	3.5	3.5	1.8	1.8	5.2	3.5
4.5-in. Hg	2.3	2.3	2.3	2.3	5.3	5.3	3.5	3.5	3.5	2.3	2.3	5.3	3.6
5-in. Hg	2.5	2.5	2.5	2.5	5.3	5.3	3.5	3.5	3.5	2.5	2.5	5.3	3.6
Fuel Economy, mpg													
City	26	28	30	29	27	26	30	26	30	24	27	23	27
Highway	34	40	43	44	35	35	42	39	43	34	41	31	41
Exhaust Emissions, g/m													
HC	1.5	1.2	-	1.3	0.5	0.6	-	0.6	0.5	1.2	1.2	0.4	0.4
CO	9	9	-	10	4	6	-	5	3	13	7	6	3
NO_x	2.9	2.1	-	1.9	1.6	1.4	-	1.6	1.5	2.2	2.4	1.6	1.6

5.6.4.3 Ignition System

5.6.4.3.1 Design Features

A conventional breaker-point ignition system is used in the 49-states vehicles, whereas the California vehicles are equipped with a transistorized ignition system which is functionally identical to the unit used in the 119.1-CID engine.

As shown in Table 5-16, a number of auxiliary emission control devices are used in some of the 85.2-CID engines, including a deceleration device, a spark delay system for automatic transmission equipped vehicles, and a spark retard system for vehicles with manual transmission. These units are similar to those previously described in Section 5.6.3.3.3.

5.6.4.3.2 Spark Advance Schedules

The nominal centrifugal and vacuum advance settings and the basic timing for the 85.2-CID engine are listed in Table 5-18. As indicated, the centrifugal advance schedules are nearly the same for all engines, except for the 1976 California and 49-states configurations with manual transmission, which use slightly lower advance in the mid-speed regime. However, this reduction is accompanied by substantially higher vacuum advance settings.

Identical vacuum advance schedules are employed in the 1975 and 1976 California and 49-states vehicles with automatic transmission, varying between 0 crankshaft deg for vacuum signals below 7-in. Hg to about 13 crankshaft deg for 12-in. Hg signal vacuum. Conversely, the vacuum advance of the manual transmission equipped vehicles has been modified in 1976 relative to 1975, particularly in the low vacuum regime.

The operation of the spark retard systems used in the 1975 and 1976 vehicles with manual transmission is illustrated in Figure 5-20, showing the standard vacuum advance used in neutral, as well as in fourth and fifth gear, and the retarded advance curves, which are effective in first, second, and third gear. In addition to the spark advance modifications discussed, the calibration tolerances have been reduced in 1976 by 50 percent from the 1975 levels of about ±3 crankshaft deg for centrifugal advance and ±2 to ±5 crankshaft deg for vacuum advance.

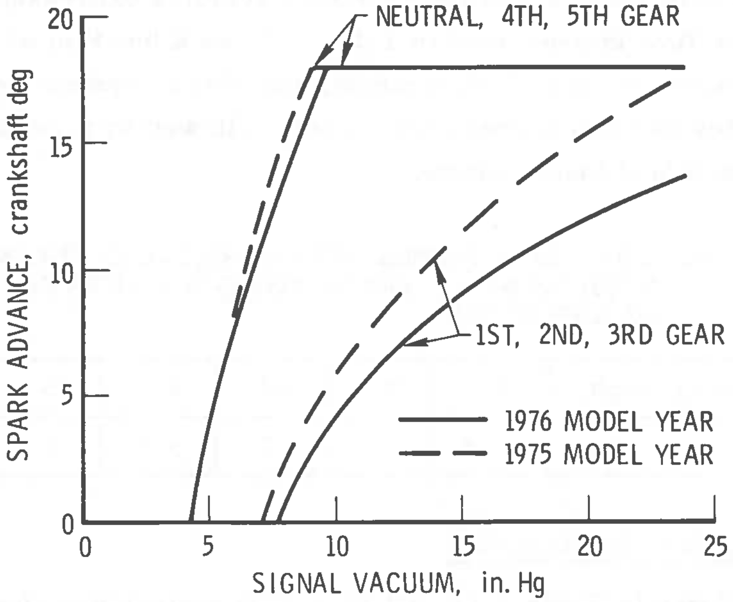


FIGURE 5-20. EFFECT OF IGNITION RETARD SYSTEM ON VACUUM ADVANCE: NISSAN 85.2-CID ENGINE WITH MANUAL TRANSMISSION

5.6.4.4 Exhaust Gas Recirculation

5.6.4.4.1 Design Features

The EGR system used in the 85.2-CID engine is functionally identical to the system described in Section 5.6.3.4, consisting of a carburetor port vacuum-controlled EGR valve and a coolant temperature control system.

5.6.4.4.2 EGR Valve Calibration

EGR valve calibration data for the 85.2-CID are presented in Table 5-18, listing the signal vacuum to open the valve and the nominal EGR valve flow rates as a function of the applied vacuum signal. Because of the more stringent 1975/76 California NO_x standard, the vehicles calibrated for use in California require more EGR than the 49-states vehicles. To provide more precise EGR control and better EGR system performance, the EGR valve calibration tolerances have been reduced to about ±0.3 cfm in 1976 compared with about ±0.7 cfm in 1975.

The EGR flow rate of the 49-states vehicles expressed as a percentage of engine flow is presented in Table 5-19 as a function of vehicle speed. Like most other current EGR systems, the Nissan system provides increasing EGR rates as vehicle speed increases, followed by a reduction in EGR in the high speed (and load) regime.

TABLE 5-19. EGR FLOW RATES: NISSAN 85.2-CID ENGINE WITH MANUAL TRANSMISSION; 49-STATES CALIBRATION

Vehicle Speed, mph	31	37	43	50	55
EGR, %	2.5	7	7	5.5	4

5.6.4.5 Secondary Air Injection

As shown in Table 5-18, all 85.2-CID engines are equipped with a secondary air injection system which is similar in design to the system previously described for the 119.1-CID engine.

5.6.4.6 Catalytic Converter

The California vehicles are equipped with a catalytic converter system consisting of a monolithic catalyst, two temperature sensors and a warning light. The system is identical to that used in the 119.1-CID engine.

5.6.4.7 Crankcase and Evaporative Emission Control

The CCV system and the evaporative emission control system used in the 85.2-CID engine are of conventional design and similar to the configurations described in Section 3.

5.6.4.8 Fuel Economy and Emissions

The fuel economy and emission data for the Nissan 49-states and California certification vehicles are listed in Table 5-18. (Refs. 5-8 through 5-11 and 5-13). Figure 5-21 presents the normalized average city fuel economy computed from the certification values in accordance with the procedure outlined in Section 3. Since no clear trend in city fuel economy is apparent between the 4- and 5-speed manual transmissions, the data for both transmissions are combined in Figure 5-21 to increase the data sample for this particular vehicle category. Conversely, the normalized highway fuel economy of the vehicles with 5-speed manual transmission is about 1-2 mpg better than for the four-speed transmissions. Considering the use of higher EGR flow rates in the California calibrations, it is somewhat surprising that the fuel economy of both the California and 49-states vehicles are generally similar.

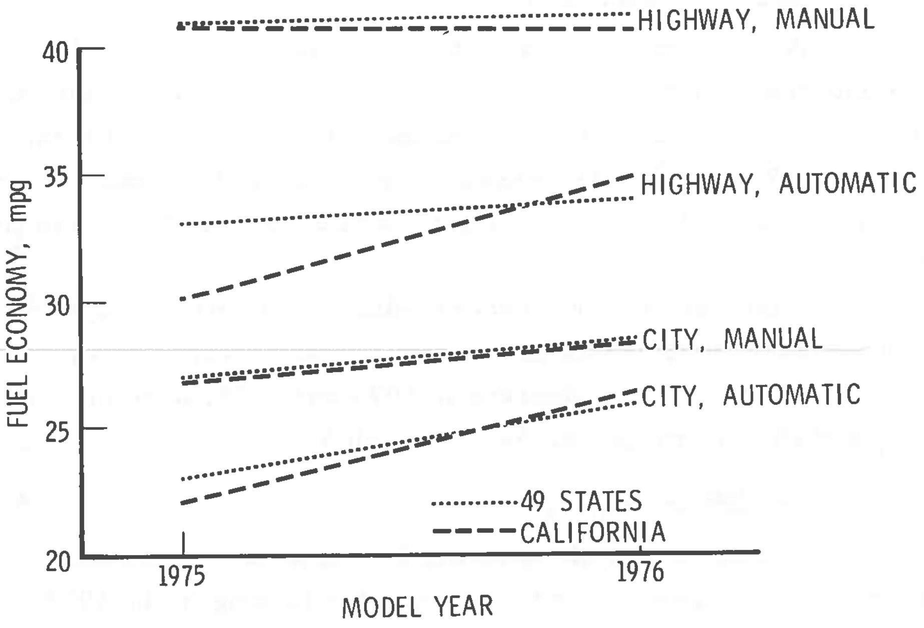


FIGURE 5-21. NORMALIZED AVERAGE FUEL ECONOMY: NISSAN 85.2-CID ENGINE

Figure 5-21 shows that the city fuel economy of the 49-states vehicles with automatic or manual transmission increases slightly between 1975 and 1976. Although the available data sample is small, the observed improvements in 1976 may be attributed to the use of tighter carburetor, distributor, and EGR system calibration tolerances in 1976. As previously noted, the nominal air/fuel ratio, spark advance and EGR valve settings are nearly constant for the two model years.

5.7 PEUGEOT

5.7.1 Engine/Vehicle Configurations

Peugeot's 4-cylinder, water-cooled engine of 120.3-CID has been selected for examination in this study. The engine was introduced in 1971 for use in the Peugeot 504 model sedan and station wagon vehicles. Prior to 1975, the 49-states and California vehicles are identical for a given model year, with minor emission control related differences appearing in 1975 and 1976.

5.7.2 Engine Design Features

As illustrated in Table 5-20, the basic design of the engine has remained unchanged since 1971 except for the addition of emission control equipment in later years. The compression ratio was reduced from 8.4 in 1971 to 7.6 in 1972, but was increased again to 8.0 in 1975 and 1976 to improve vehicle fuel economy while maintaining compatibility with 91 octane (RON) gasoline.

Intake and exhaust valve timing modifications were implemented in 1974 and again in 1975. This has resulted in an increase in valve overlap from 0 degrees in 1972 to 9.5 degrees in 1975 and 1976, accompanied by additional NO_x and HC control (Refs. 5-54 through 5-61).

5.7.3 Air Intake System

Heating of the air entering the air cleaner, provided in 1972, was discontinued in following model years. Air heating in the 1972 vehicles is accomplished by means of a metal sleeve placed around the exhaust manifold. Intake air temperature control is maintained by means of a flapper valve located in the air intake duct and actuated by a temperature sensing element. For air cleaner temperatures below 68°F, the valve is fully open and the intake air is drawn through the heater. Above 68°F, the valve starts to open, and a mixture of heated air and cooler engine compartment air is admitted to the air cleaner.

5.7.4 Carburetor

5.7.4.1 Design Features

All 1972-1976 model year Peugeot 120.3-CID engines are

TABLE 5-20. ENGINE SPECIFICATIONS: PEUGEOT 120.3-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4	
Bore, in.	3.464		3.464		3.464		3.464	
Stroke, in.	3.189		3.189		3.189		3.189	
Displacement, cu in.	120.3		120.3		120.3		120.3	
Surface/Volume, 1/in.	5.9		5.9		5.9		5.9	
Compression Ratio	8.0		8.0		7.6		7.6	
Cylinder Head Type	-		-		-		-	
Advertised HP at Engine Speed, rpm	88 at 5500		88 at 5500		82.6 at 5200		87 at 5250	
Torque, ft-lb, at Engine Speed, rpm	110 at 2900		110 at 2900		102.7 at 3000		112 at 3000	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Hemisphere		Hemisphere		Hemisphere		Hemisphere	
Intake Valve Diameter, in.	1.615		1.615		1.615		1.615	
Intake Valve Lift, in.	0.351		0.351		0.328		0.328	
Exhaust Valve Diameter, in.	1.319		1.319		1.319		1.319	
Exhaust Valve Lift, in.	0.351		0.351		0.328		0.328	
Intake Valve Opens, deg BTC	4.5		4.5		-2		-4	
Intake Valve Closes, deg ABC	40		40		39		34	
Intake Valve Duration, deg	224.5		224.5		217		210	
Exhaust Valve Opens, deg BBC	38		38		30		34	
Exhaust Valve Closes, deg ATC	5		5		8.5		4	
Exhaust Valve Duration, deg	223		223		218.5		218	
Valve Overlap, deg	9.5		9.5		6.5		0	
Distributor Type	Breaker point		Breaker point		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC	5		5		5		5	
Idle Speed, rpm	900		900		800		800	
Fast Idle Speed, rpm	-	1400	-	1400	1400		1400	
Fuel System Type	1V downdraft Solex (2)		1V downdraft Solex (2)		1V downdraft Solex (2)		1V downdraft Solex (2)	
Fuel Metering Method	-		-		-		-	
Enrichment Method	Econostat valve in 2V carburetor		Econostat valve in 2V carburetor		Econostat valve in 2V carburetor		-	
Choke Type	Manual with automatic override		Manual with automatic override		Manual		Manual	
Carburetor Venturi Diameter, in.	0.945 (1V) 1.031 (2V)		0.945 (1V) 1.031 (2V)		0.945 (1V) 1.031 (2V)		0.945 (1V) 1.031 (2V)	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	195 at 1.6		195 at 1.6		195 at 1.6		-	
Emission Control Systems	AIR EVAP PCV Thermal reactor		AIR EVAP PCV Thermal reactor		AIR EVAP PCV		EVAP PCV	
Emission Control Devices	Deceleration device[a]		Deceleration device[a]		-		Deceleration device	

[a] California only

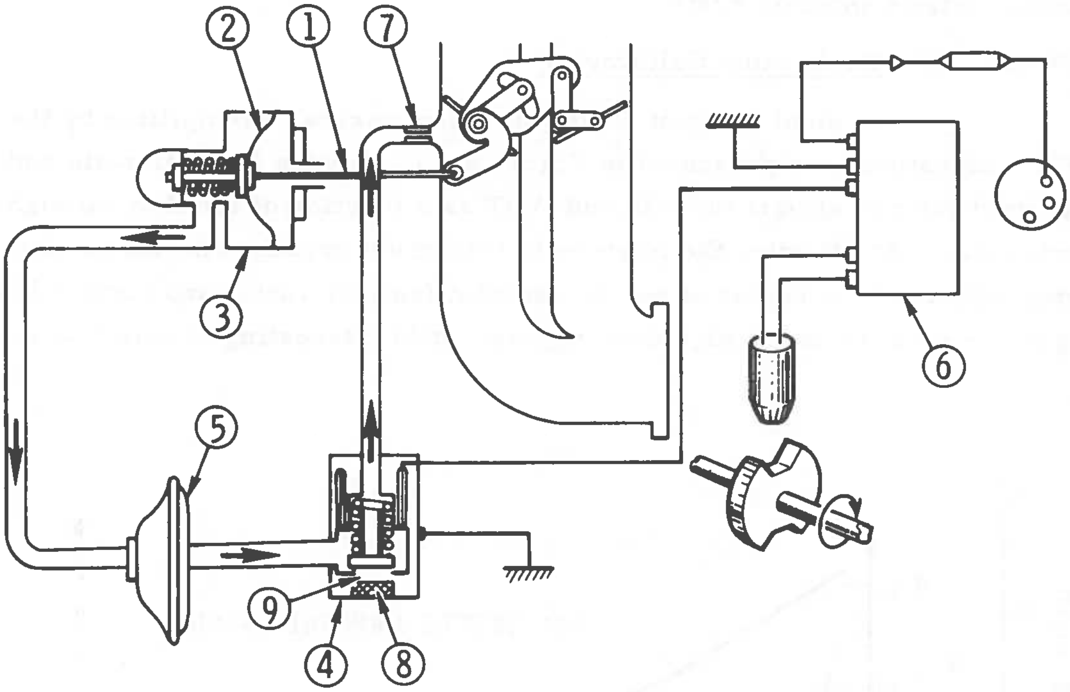
equipped with two single-venturi, downdraft-type Solex carburetors (Model Nos. 32BICSA2 and 34PBIC8). Each unit is of conventional design, employing idle jets and main jets, as well as economizer jets, to provide improved mixture control under cruise and full-load operating conditions of the engine. For more precise air/fuel ratio control at low loads, the throttle of the second carburetor remains closed until the accelerator pedal is depressed about one-third of its full travel. To assist in the control of HC and CO during vehicle deceleration, a deceleration control unit is used in most engines, combined with a fast idle speed setting in the 1975 and 1976 California vehicles. The combination of staged carburetor operation, deceleration control, and fast idle constitutes Peugeot's Coppolair anti-pollution system.

The operating principle of the fast idle control system is illustrated in Figure 5-22. When the lever (1) is pulled to the left by the movement of the diaphragm (2), a throttle stop is provided which prevents complete closing of the throttle plate. The vacuum unit (3) is subjected to manifold vacuum via a three-way solenoid valve (4) and a vacuum damper (5). For vehicle speeds below 25 mph during acceleration and below 22 mph during deceleration, this valve is energized by the electronic control unit (6). In this case, the vacuum supply (7) to the vacuum unit is interrupted and ambient pressure supplied through a filter (8) and air passage (9) forces the control lever (1) into its neutral position. As a result, the fast idle feature is deactivated. Conversely, the solenoid valve is de-energized above these speed settings, and the fast idle position is restored.

To prevent dieseling of the engine two solenoid valves are used which close the fuel supply when the ignition key is turned off.

Except for small variations in the venturi size of the first carburetor and the elimination of the deceleration control and fast idle features, the carburetor used in 1974 is similar to the 1972 unit. As discussed in Section 5.7.7 the function of providing additional air during deceleration is performed by the air injection system.

The carburetors used in 1975 and 1976 model 49-states vehicles are similar to the 1974 design, except for the addition of an automatic override of the manual choke to prevent closing of the choke when the engine is warm. This system, which consists of a coolant temperature sensor and an electric motor, is designed to deactivate the choke for coolant temperatures



LEGEND

1. CONTROL LEVER
2. DIAPHRAGM
3. VACUUM UNIT
4. 3-WAY SOLENOID VALVE
5. VACUUM DAMPER
6. ELECTRONIC CONTROL UNIT
7. VACUUM SUPPLY
8. FILTER
9. AIR PASSAGE

FIGURE 5-22. FAST IDLE CONTROL SYSTEM: PEUGEOT 120.3-CID ENGINE above 120°F. The 1975 and 1976 California carburetors are similar to the corresponding 49-states configurations, except for the addition of the previously noted Coppolair system.

5.7.4.2 Carburetor Calibration

Typical Peugeot carburetor flow curves, exemplified by the 1976 calibration, are presented in Figure 5-23, showing fuel/air ratio and manifold vacuum at part throttle and WOT as a function of air flow through the carburetor. At off-idle, the mixture is leaned out rapidly with increasing flow rate, followed by a region of nearly constant fuel/air ratio, and further leaning of the mixture in the high flow regime. It is interesting to note that leaner mixtures are employed at full throttle. This approach was selected by Peugeot in conjunction with other adjustments to meet the 1975/76 NO_x emission standards without the use of EGR, but at the expense of a loss in maximum engine power output.

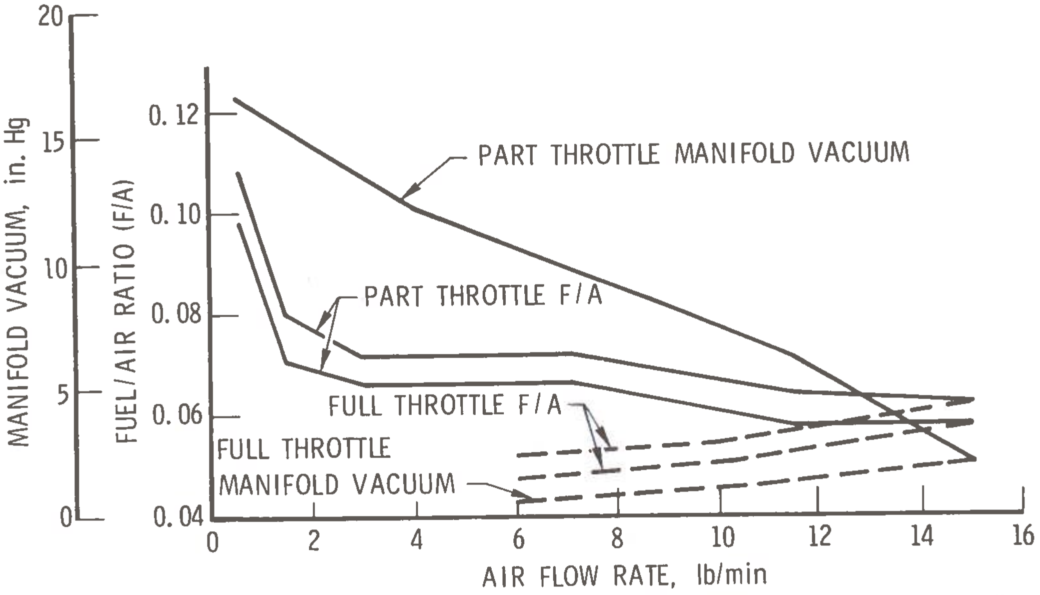


FIGURE 5-23. CARBURETOR CALIBRATION: 1976 PEUGEOT 120.3-CID ENGINE

Carburetor calibration data for other model year engines are listed in Table 5-21, showing the nominal air/fuel ratio at discrete carburetor air flow settings. As indicated in the table, the air/fuel ratio schedules remained nearly constant between 1974 and 1976, except for the small 1975 increase at WOT. No reliable calibration data are available for the 1972 model year. The calibration tolerances have been reduced in 1976 to about ±5 percent at idle and cruise and ±4 percent at WOT, compared with the 1975 levels of about ±6 percent at idle, ±9 percent during cruise, and ±4 percent at WOT.

5.7.5 Ignition System

As shown in Table 5-20, all 120.3-CID engines employ a conventional breaker-point ignition system. Unlike most other manufacturers, Peugeot does not use vacuum spark advance. The centrifugal advance settings and the basic timing for the 1974-1976 vehicles are listed in Table 5-21, indicating no change in spark timing for this time period. The calibration tolerances are ±2 crankshaft deg.

5.7.6 Exhaust Gas Recirculation

EGR is not used by Peugeot, and NO_x control is achieved by spark timing and air/fuel ratio control.

5.7.7 Secondary Air Injection

All 1974 and later model year engines are equipped with an exhaust manifold air injection system. This system, which carries the HC and CO emission control burden, is of conventional design, consisting of an air pump, a pressure relief valve, a control valve for air modulation during vehicle deceleration, and an anti-backfire valve. In addition, a modified cylinder head is used which incorporates the four injection passages supplying air into the cylinder exhaust ports. The engine-driven vane-type air pump has a maximum capacity of 2.5 lb/min. In addition to providing air into the exhaust manifold, some of the secondary air is injected into the intake manifold during vehicle deceleration. This results in leaner mixtures and lower HC and CO emissions.

For additional HC and CO control, the 1974-1976 model year vehicles are equipped with a thermal reactor which is attached to the exhaust

TABLE 5-21. CERTIFICATION CALIBRATION DATA: PEUGEOT 120.3-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter[a]	Model Year and Certification Standard											
	1976 49 States			1976 California			1975 49 States		1975 California		1974 49 States and California[b]	
Vehicle Model	504[c]	504[d]	504[c]	504[c]	504[d]	504[c]	504[d]	504[c]	504[c]	504[d]	504[c]	504[c]
Transmission Type	A3	A3	M4	A3	A3	M4	A3	M4	A3	M4	A3	M4
Vehicle Inertia Weight, lb	3500	3500	3500	3500	3500	3500	3500	3000	3000	3500	3000	3000
Rear Axle Ratio	3.89	4.11	3.89	3.89	4.11	3.89	4.11	3.89	3.89	4.11	3.78	3.78
Catalyst	No	No	No	No	No	No	No	No	No	No	No	No
Carburetor Calibration, A/F												
Idle: 0.4-lb/min air flow	9.7	9.7	9.7	9.7	9.7	9.7	9.5	9.5	9.5	9.5	9.3	9.3
Off Idle: 0.8-lb/min air flow	10.9	10.9	10.9	10.9	10.9	10.9	11.1	11.1	11.1	11.1	10.5	10.5
Part Throttle: 5-lb/min air flow	14.4	14.4	14.4	14.4	14.4	14.4	14.5	14.5	14.5	14.5	14.7	14.7
WOT: 15-lb/min air flow	16.6	16.6	16.6	16.6	16.6	16.6	16.7	16.7	16.7	16.7	15.9	15.9
Basic Timing, crankshaft deg BTC	5	5	5	5	5	5	5	5	5	5	5	5
Centrifugal Advance, crankshaft deg												
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	1	1	1	1	1	1	1	1	1	1	1	1
2000 rpm	8	8	8	8	8	8	8	8	8	8	8	8
3000 rpm	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
4000 rpm	32	32	32	32	32	32	32	32	32	32	32	32
5000 rpm	32	32	32	32	32	32	32	32	32	32	32	32
Fuel Economy, mpg												
City	17	17	17	16	17	16	17	25	19	17	17[e]	16.8[e]
Highway	22	22	24	21	21	23	20	27	26	22	-	-
Exhaust Emissions, g/m												
HC	0.3[f]	0.3[f]	0.5[f]	0.2[f]	0.3[f]	0.6[f]	0.4	0.9	0.3	0.5	0.6[e]	1.3[e]
CO	10[f]	9[f]	7[f]	7[f]	9[f]	9[f]	9	8	7.6	7.1	2.5[e]	14[e]
NO_x	1.7[f]	1.5[f]	1.0[f]	1.2[f]	1.0[f]	1.0[f]	1.3	1.0	1.0	1.3	1.3[e]	1.0[e]

[a] Vacuum advance is not used; EGR is not used.

[b] 1973 carryover vehicle

[c] 504 sedan

[d] 504 sedan; 504 wagon

[e] 1972 FTP

[f] 4000-mile data

manifold. The reactor, which has a volume of 70 cu in. is made of Inconel 600 and is insulated externally with Kalane insulation.

5.7.8 Catalytic Converter

Peugeot does not use catalysts for HC and CO control, relying entirely on the thermal reactor secondary air system, combined with appropriate carburetor and distributor settings.

5.7.9 Crankcase and Evaporative Emission Control

The CCV system used by Peugeot is of conventional design. At low loads, the crankcase vapors are drawn through an oil separator and a small orifice into the intake manifold. As the throttle opens, intake manifold vacuum decreases, and most of the crankcase vapors are then inducted into the intake below the air cleaner by means of a second vent line. For intermediate loads, both circuits operate concurrently.

The evaporative emission control system is functionally identical to the system described in Section 3.

5.7.10 Fuel Economy and Emissions

The available fuel economy data for the Peugeot 1974-1976 certification vehicles are listed in Table 5-21 (Refs. 5-8 through 5-11 and 5-13). These data were normalized and adjusted to account for differences in the test procedure, using the method described in Section 3.1. The resulting data are presented in Figure 5-24, showing the average city and highway fuel economy of the 49-states and California vehicles as a function of model year.

The normalized city fuel economy shown in Figure 5-24 for 1973 and 1974 is identical because the 1974 vehicles are carry overs from 1973 (Refs. 5-13 and 5-20). Since the carburetor and distributor calibrations remain unchanged between 1974 and 1976, the small rise in the 1975 city fuel economy of the 49-states vehicles with manual transmission might be attributed to the higher compression ratio used in 1975 and 1976. However, since no change in fuel economy is indicated for the 49-states automatic transmission vehicles, the observed improvement for the manual transmission might be the result of test-to-test and vehicle-to-vehicle variabilities. In view of the small data sample available for each model year, variations of this magnitude are not

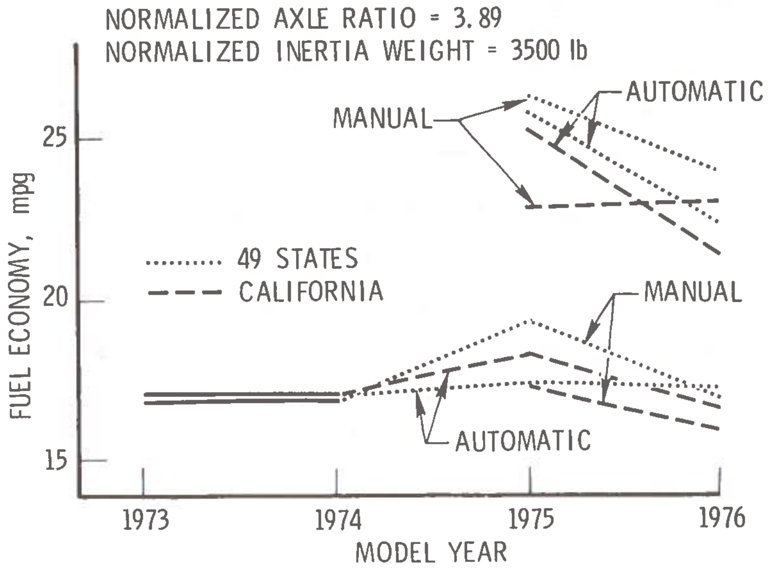


FIGURE 5-24. NORMALIZED AVERAGE CITY FUEL ECONOMY: PEUGEOT 120.3-CID ENGINE

considered to be unreasonable. The observed reductions in both city and highway fuel economy in 1976 are difficult to explain considering that identical emission control systems and component calibrations are used in 1975 and 1976. Again, the differences are small and might be due to test variations. Similar variations are observed for the California vehicles.

The city fuel economy of the 1975 and 1976 California vehicles is of the order of 5 percent lower than for the 49-states vehicles. This decline is attributed to the application of the Coppolair system and the fast idle speed setting used during deceleration.

While the fuel economy of the 1973 and 1974 vehicles with automatic and manual transmission is essentially identical, the manual transmission shows consistently better city and highway fuel economy in 1975 and 1976, except for the California vehicles with manual transmission which have the same highway fuel economy in 1975 and 1976.

As indicated in Table 5-21, the already low 1973 and 1974 HC and CO emissions have been further reduced in 1975 through the use of a thermal reactor. In addition to the thermal reactor system, the California vehicles are equipped with a deceleration system which provides further HC and CO control during periods of vehicle deceleration.

Because nearly the same calibration settings are used nationwide, the NO_x emissions show little change between 1973 and 1976 for both 49-states and California vehicles. In the absence of EGR and significant valve overlap, the low NO_x levels are attributed to the lean air/fuel ratios in the cruise and high-load regimes and the relatively low spark advance at low and medium engine speeds. It should be noted that the 1976 emissions are 4000-mile data. However, since no catalyst is used, the system deterioration factors should be near unity, and the listed emission data should approximate the 50,000 mile certification values.

5.8 SAAB

5.8.1 Engine/Vehicle Configurations

The Saab 121-CID overhead cam engine teamed with vehicles of 2750- and 3000-pounds inertia weight comprise the engine/vehicle configurations chosen to characterize Saab engine control methods. Saab designates the subject vehicle as the 99 series and offers two-door, four-door and hatchback models with either four-speed manual or three-speed automatic transmissions. Model years of interest for purposes of this report are 1974-1976.

5.8.2 Engine Design Features

Table 5-22 presents engine design particulars for the 1974-1976 model years (Refs. 5-62 through 5-69). Major year-to-year engine changes are centered about the fuel delivery system with continuous fuel injection replacing carburetor or timed fuel injection systems, which have been used prior to the 1975 model year.

5.8.3 Engine Modifications

For all model years of interest, Saab uses a bathtub combustion chamber configuration, an 8.7:1 compression ratio, and a surface-to-volume ratio of 6.44 per inch. Valve timing is the same for the 49-states and California vehicles, with some change noted between the 1974 and 1975 model

TABLE 5-22. ENGINE SPECIFICATIONS: SAAB 121-CID ENGINE

Engine Parameter	Model Year					
	1976		1975		1974	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4	
Bore, in.	3.54		3.54		3.54	
Stroke, in.	3.07		3.07		3.07	
Displacement, cu in.	121		121		121	
Surface/Volume, 1/in.	6.44		6.44		6.44	
Compression Ratio	8.7		8.7		8.7	
Cylinder Head Type	OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	115 at 5500	110 at 5500	115 at 5500	110 at 5500	110 at 5500 (FI) 95 at 5200 (CARB)	
Torque, ft-lb, at Engine Speed, rpm	123 at 3500	119 at 3500	123 at 3500	119 at 3500	123 at 3700 (FI) 115 at 3500 (CARB)	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Bathtub		Bathtub		Bathtub	
Intake Valve Diameter, in.	1.65		1.65		1.65	
Intake Valve Lift, in.	0.426		0.426		0.39	
Exhaust Valve Diameter, in.	1.40		1.40		1.40	
Exhaust Valve Lift, in.	0.434		0.434		0.39	
Intake Valve Opens, deg BTC	10		10		12	
Intake Valve Closes, deg ABC	54		54		56	
Intake Valve Duration, deg	244		244		248	
Exhaust Valve Opens, deg BBC	46		46		56	
Exhaust Valve Closes, deg ATC	18		18		12	
Exhaust Valve Duration, deg	244		244		248	
Valve Overlap, deg	28		28		24	
Distributor Type	Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance		Breaker point; centrifugal and vacuum advance (FI); vacuum advance (CARB)	
Basic Ignition Advance, deg BTC	14 at 800	12 at 800	14 at 800	12 at 800	8 at 800 (FI) 14 at 800 (CARB)	
Idle Speed, rpm[a]	875		875		800 (A) 850 (M)	
Fast Idle Speed, rpm	-		-		-	
Intake Air Temperature Control	Uncontrolled		Uncontrolled		Uncontrolled (FI) Thermostatic (CARB)	
Fuel System Type	Continuous FI		Continuous FI		Timed FI or 1V CARB	
Fuel Metering Method	Regulated by air flow rate		Regulated by air flow rate		Change injection time (FI); tapered rod (CARB)	
Enrichment Method	Temperature-regulated fuel pressure		Temperature-regulated fuel pressure		Change injection time (FI); oil damp air valve (CARB)	
Choke Type	Cold-start injection		Cold-start injection		Cold-start injection (FI); Manual (CARB)	
Carburetor Venturi Diameter, in.	-		-		1.75	
Fuel System Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	157 at		157 at		167 at (FI) 146 at 8 (CARB)	
Emission Control Systems	EGR[b] EVAP FI PCV	AIR EGR[c] EVAP FI PCV	EGR[b] EVAP FI PCV	AIR EGR[c] EVAP FI PCV	EM[d] EVAP FI PCV	
Emission Control Devices	Deceleration valve EGR cold engine COS EGR service indicator	EGR vacuum COS	Deceleration valve EGR cold engine COS EGR service indicator	EGR vacuum COS	Deceleration valve (CARB)	

[a] A = automatic transmission; M = manual transmission

[b] Used only on automatic transmission vehicles

[c] Proportional EGR

[d] Used only on carburetor-equipped engines

years. As shown in Table 5-22, total overlap increases from 24 deg in 1974 to 28 deg in 1975. Since the additional overlap is obtained by increasing exhaust valve closing delay while decreasing intake valve opening advance, the additional overlap is likely for the purpose of NO_x control (Ref. 5-70).

5.8.4 Intake System

Fuel-injected engines for the three model years of interest do not use a temperature-controlled air inlet system, but the 1974 carburetor version of the subject engine does. The system is a conventional one which employs an exhaust manifold-mounted heat stove to supply heated air to an air control valve which is controlled by an air temperature sensor in the air cleaner. Nominally constant temperature air is provided to the carburetor by the air control valve, which mixes underhood and heated air to maintain the desired temperature.

5.8.5 Fuel System

5.8.5.1 Continuous Fuel Injection and Carburetor

Over the three model years of interest, Saab offers two types of fuel injection and one carburetor-based fuel distribution system. For 1975 and 1976, the same type of continuous fuel injection system used by Audi is employed by Saab. This is the Bosch continuous injection system (CIS) presented in Section 5.1.3.3. As operation of the system is described in the Audi section of this report it is not repeated here. However, it is noted that for 1976 Saab has added an acceleration enrichment function not described in Section 5.1.3.3. This function is implemented by use of the existing cold start injector which normally injects fuel into the common intake manifold only during engine startup. In its role as an acceleration enrichment device, it is modulated by an intake manifold pressure sensor which causes it to inject a fuel charge of up to 0.5 seconds in duration whenever intake manifold vacuum drops. The system has a thermal override switch that defeats the acceleration enrichment function as the engine reaches its normal operating temperature. In other aspects, the Saab system operates in essentially the same manner as the Audi system.

In 1974, Saab offered either timed fuel injection or a single, one-venturi carburetor fuel distribution system on vehicles intended for sale in the United States. The carburetor-based system is of the constant depression type and is functionally much the same as the system used by British Leyland. As the functional description of the Saab system closely parallels the description provided in the British Leyland section of this report, it is not repeated here; however, Table 5-23 provides air/fuel ratio data for the subject carburetor. In addition, it is noted that the carburetor employs a throttle closing damper and a deceleration control valve which is actuated by manifold vacuum and provides additional air to the engine during engine decelerations. Table 5-22 provides further details regarding the subject carburetor.

5.8.5.2 Timed Fuel Injection System

The Bosch timed fuel injection system used on Saab engines prior to 1975 meters fuel to each cylinder by maintaining constant fuel pressure to the injectors and controlling the duration of injection time. Duration is computed by an electronic control unit based on the parameters of engine speed and load. The engine speed signal is provided to the control unit by a pair of contacts in the distributor, while an absolute pressure transducer in the air inlet duct provides a measure of engine load.

A commencement-of-injection signal is provided to the control unit by a pair of contacts mounted in the distributor. Injectors for the four cylinders are actuated in groups of two. This results in fuel being injected directly into open intake valves on two engine cylinders and on closed intake valves on the remaining two cylinders. In the latter case, fuel is stored in the vicinity of the intake valve until the valve opens and the inlet air stream sweeps the fuel charge into the combustion chamber.

Air is supplied to the four cylinders through four individual induction pipes connected to a common inlet duct, where air flow is controlled by a throttle valve. For idle operation, the throttle is completely closed, and idle air enters the inlet duct via a bypass port behind the throttle valve. The effective cross sectional area of the bypass port is controlled by an auxiliary air valve regulated by engine coolant temperature in a manner which provides increased air flow and attendant higher engine idle speeds during warmup.

TABLE 5-23. CERTIFICATION CALIBRATION DATA: SAAB 121-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard												
	1976 49 States		1976 California		1975 49 States			1975 California		1974 49 States and California			
Vehicle Model	99	99	99	99	99LE	99LE	99LE	99LE	99LE	99LE	99LE	99LE	99[a]
Transmission Type	M4	A3	M4	A3	M4	M4	A3	M4	A3	M4	M4	A3	A3
Vehicle Inertia Weight, lb	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	2750	3000	2750
Rear Axle Ratio	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89
Catalyst	No	No	No	No	No	No	No	No	No	No	No	No	No
No. of Carburetor Venturi's	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	1
Carburetor Calibration, A/F													
Idle: 0.8-lb/min air flow	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	-	-	-	11.2
Off Idle: 1.5-lb/min air flow	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	-	-	-	12.8
Part Throttle: 4.4-lb/min air flow	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	-	-	-	13.5
WOT at Max.: 11.8-lb/min air flow	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	-	-	-	-
Basic Timing, crankshaft deg BTC	14	14	12	12	14	14	14	12	12	8	8	8	14
Centrifugal Advance, crankshaft deg													
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	10.0
2000 rpm	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	17.0
3000 rpm	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	21.0
4000 rpm	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	24.0
5000 rpm	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	27.0	27.0	27.0	24.0
Vacuum Advance, crankshaft deg													
200 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
250 mm Hg	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	-
300 mm Hg	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	-
350 mm Hg	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	-
400 mm Hg	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	-
EGR Valve Calibration													
Signal Pressure To Open, mm Hg	-	55	57	57	-	-	55	57	57	-	-	-	-
Flow at 175-mm Hg, cfm	-	3.2	10.5	10.5	-	-	3.2	10.5	10.5	-	-	-	-
Fuel Economy, mpg													
City	21	18	19	18	23	21	21	21	21	17.0[b]	19.4[b]	16.1[b]	18.8[b]
Highway	30	25	28	23	30	31	23	28	23	-	-	-	-
Exhaust Emissions, g/m													
HC	-	-	0.9	0.6	1.1	1.5	1.4	0.6	0.9	2.8[b]	2.7[b]	1.7[b]	1.7[b]
CO	-	-	6.2	7.1	6.0	9.0	7.0	5.9	7.3	30.0[b]	18.0[b]	18.0[b]	24.0[b]
NO_x	-	-	1.8	1.6	2.1	2.3	1.8	1.8	1.3	1.7[b]	1.8[b]	2.4[b]	2.2[b]

[a] Carbureted engine; vacuum advance is not used

[b] 1972 FTP

In addition to scheduling fuel injector duration time as a function of engine speed and engine load, an additional amount of fuel is injected when starting the engine at low ambient temperatures, during warm-up, and during acceleration. Enrichment during engine start is provided by a single cold start injector situated in the air inlet duct. The cold start injector provides fuel only when the starter is operating and engine coolant temperature is below 41°F. After engine startup, mixture enrichment is obtained by providing the control unit with electrical signals proportional to intake air temperature and engine coolant temperature. The control unit uses these two signals to schedule additional injector open time for operation in cold ambient air and during engine warmup. Temporary enrichment during acceleration is provided by a throttle valve switch which signals the control unit when the accelerator is depressed. In addition, this switch provides a closed throttle signal, which causes the control unit to shut off the fuel supply when the throttle is closed and engine speed is above 1600 rpm. As engine speed drops below 100 rpm, the fuel supply is switched on again in order to provide a smooth transition to idle operation. When the engine is cold the speed range is raised by 300 rpm to compensate for higher engine friction levels. Figure 5-25 provides the basic injector duration time schedule as a function of engine speed and pressure in the inlet manifold.

5.8.6 Ignition System

5.8.6.1 Design Features

For the 1974-1976 models, Saab has used a breaker-point ignition system. The system is conventional, except that 1974 and earlier fuel-injected engines use a special set of cam-operated switch contacts incorporated in the distributor to provide timing signals to the electronic control module of the fuel injection system.

5.8.6.2 Ignition Advance

For the 121-CID engine, Saab employs conventional centrifugal and vacuum advance when fuel injection is used. On 1974 carbureted versions of the engine, only centrifugal advance is fitted, and in no case is transmission-controlled spark used. Except for basic advance differences shown in Table 5-23, the 49-states and California engines use the same ignition advance

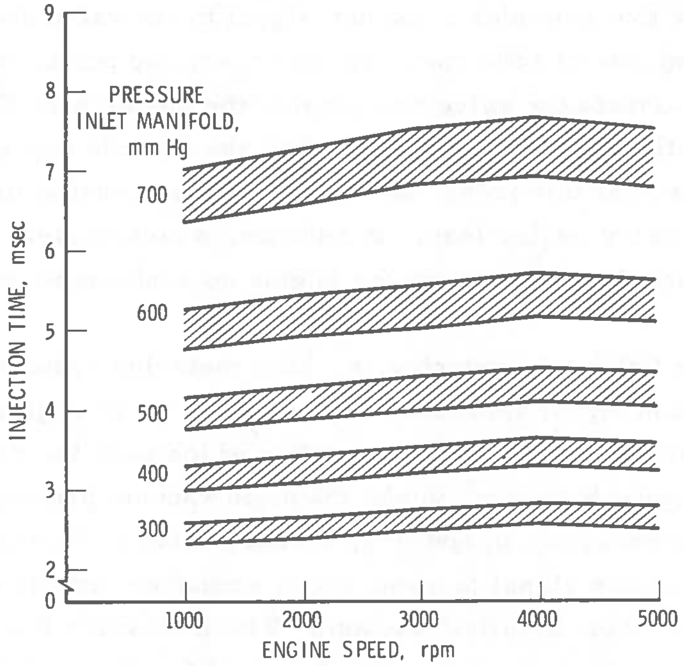


FIGURE 5-25. FUEL INJECTION TIME VERSUS ENGINE SPEED AND MANIFOLD PRESSURE: 1974 SAAB 121-CID ENGINE WITH AUTOMATIC TRANSMISSION

schedule for all model years. As shown in the table, the only change in ignition timing occurs between 1974 and 1975 when basic timing is increased. This increase has a noticeable correlation with fuel economy, as discussed in Section 5.8.11.

5.8.7 Exhaust Gas Recirculation

Exhaust gas recirculation was originally incorporated in 1975 on Saab vehicles using the subject engine. Two distinct types of EGR are used, with selection based on whether the engine is intended to meet 49-states or California NO_x standards. For 49-states automatic transmission vehicles, a standard EGR system is used, while all California vehicles employ a proportional system. The 49-states manual transmission vehicles do not use EGR.

The standard EGR system uses a vacuum-actuated, spring-loaded EGR valve controlled by means of a vacuum signal obtained from the throttle valve housing. The vacuum tap is located relative to the throttle valve in a manner that provides a vacuum signal to the valve above constant unloaded engine speeds of 1800 rpm. At this operating point, vacuum is strong enough to actuate the valve and provide the engine with EGR. As the throttle opens farther EGR is maintained until the throttle approaches its wide open position. At this point, vacuum decreases causing the valve to close for conditions of heavy engine load. In addition, a cold engine cutout is provided which defeats the EGR system for engine coolant temperatures below $95^{\circ}F$.

On California vehicles, an EGR metering system provides an EGR valve actuation signal approximately proportional to engine load. The system is implemented by a vacuum amplifier which uses the relatively weak venturi vacuum signal to control intake manifold vacuum provided to the EGR valve actuating diaphragm. In addition, a relief valve is incorporated which dumps the EGR vacuum signal to atmosphere whenever venturi vacuum is equal to or greater than intake manifold vacuum. The EGR valve therefore recloses at WOT when maximum power is required from the engine. California vehicles also incorporate an EGR vacuum cutout. This device defeats EGR during deceleration and idle by blocking the vacuum signal to the EGR valve.

As in the standard system, a cold engine EGR cutout is provided, and both EGR system types have a 15,000-mile driver alert device which lights a dash-mounted lamp to indicate EGR maintenance is required. Table 5-23 presents EGR flow rate data for the standard and the proportional systems.

5.8.8 Secondary Air Injection System

In 1975, Saab introduced a conventional design of secondary air injection for use only on vehicles intended for sale in California. The air pump displaces 8.7 cu in. of air per revolution and turns 0.94 revolutions per engine revolution when used on the 121-CID engine.

5.8.9 Exhaust System

Saab does not use a catalytic converter; however, California vehicles are fitted with a slightly different exhaust manifold takeoff pipe than their 49-states counterparts. The California exhaust system uses a single pipe as opposed to the double pipe configuration employed on 49-states vehicles.

Although both systems are true single exhaust systems using one muffler, the California system provides a slightly higher backpressure and different pulse pattern than the 49-states system. Supposedly, both of these factors aid in attainment of lower emissions.

5.8.10 Crankcase and Evaporative Emission Control

Saab employs a completely closed, fixed orifice crankcase emission control system of the type described in Section 3. This system normally draws crankcase vapors directly into the inlet manifold. Under conditions of high blowby or high load, the fumes are drawn into the throttle housing.

The Saab evaporative emission control system is completely sealed, with vapors vented from the fuel filler neck to a charcoal canister mounted in the engine compartment, as described in Section 3.

5.8.11 Fuel Economy and Emissions

The fuel economy and emission data for the 1974-1976 certification vehicles are listed in Table 5-23 (Refs. 5-8 through 5-11, 5-13, and 5-29). Figures 5-26 and 5-27 present the fuel economy histories of Saab vehicles which use these data and the 1973 data taken from Ref. 5-20. Each figure presents data for vehicles with either automatic or manual transmission, and data are corrected for axle ratio, inertia weight, and test procedure as explained in Section 3.

As shown in Figures 5-26 and 5-27, the fuel economy of Saab fuel-injected vehicles declines between the 1973 and 1974 model years. This is a direct result of the more stringent 1974 California NO_x standard as all of the vehicles shown in the two figures have been certified to California standards.

Increased fuel economy between 1974 and 1975, shown in Figures 5-26 and 5-27, is a result of an increase in basic timing between these two years. The subject timing change is shown in Table 5-23. Since the increase in basic timing is accomplished without adding either a secondary air or a catalyst system to 49-states vehicles, it is not readily apparent how the 1975 HC and CO emission standards are met. Conversations (Ref. 5-71) with Saab personnel have revealed that the change from a pulsed to a continuous fuel injection system is the reason. The continuous system gives improved control of air/fuel ratio and allows an increase in spark advance without exceeding

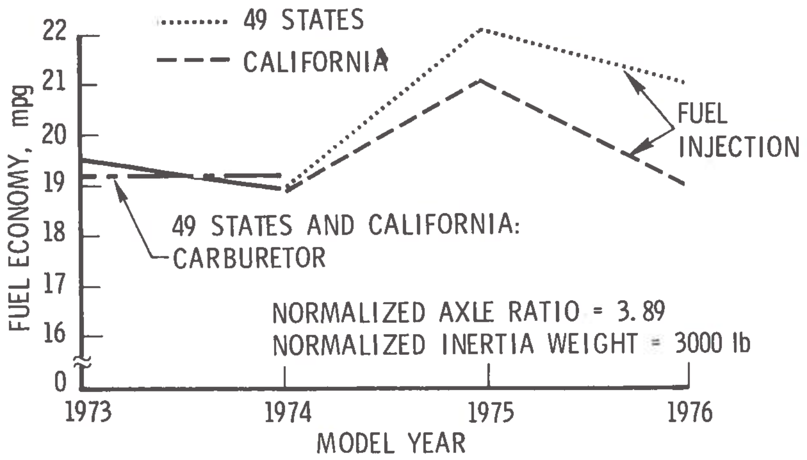


FIGURE 5-26. NORMALIZED AVERAGE CITY FUEL ECONOMY: SAAB 121-CID ENGINE WITH MANUAL TRANSMISSION

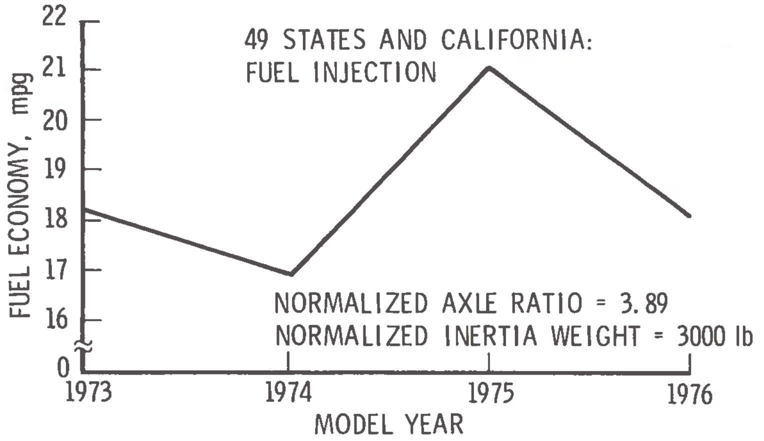


FIGURE 5-27. NORMALIZED AVERAGE CITY FUEL ECONOMY: SAAB 121-CID ENGINE WITH AUTOMATIC TRANSMISSION

statutory HC and CO levels. An increase in intake-exhaust valve overlap and the addition of EGR to 49-states vehicles with automatic transmission maintains control of NO_x in 1975. California vehicles add both secondary air and EGR in 1975 to meet the more stringent California requirements.

The decline in fuel economy between 1975 and 1976 for both automatic and manual transmission equipped vehicles is partially explained by the added acceleration enrichment used with 1976 vehicles. This feature is described in Section 5.8.5.1. In addition, some test-to-test variability is possibly a factor as 1975 EPA tests reported higher fuel economy figures than obtained in Saab factory tests (Ref. 5-71).

5.9 TOYOTA

5.9.1 Engine/Vehicle Configurations

The engines considered in this study include the Toyota 4-cylinder, water-cooled 96.9-CID and 133.6-CID designs. In 1972, the 96.9-CID engine, designated 2T-C, was fitted into Corolla and Carina vehicles. The 1974 model is designated 2T-C-EM (engine modifications) or 2T-C-AI (air injection) and is used in the Corolla-2 vehicles with either manual or automatic transmission, while the 2T-C-Fed (49-states) and 2T-C-Cal (California) engines are used in Toyota Corolla vehicles. (Refs. 5-72 through 5-79).

The 1975 and 1976 model 133.6-CID engines, designated 20R-Fed (49-states) and 20R-Cal (California), are employed in the Corona and Celica vehicles, both in conjunction with automatic or manual transmission.

5.9.2 Engine Design Features

The specifications for the Toyota 96.9-CID and 133.6-CID engines, summarized in Tables 5-24 and 5-25, respectively, indicate few engine modifications since the introduction of these engines. The 1974 model 2T-C engine used in 49-states vehicles incorporates an improved and more accurate ignition system and an improved throttle positioner for emission control during acceleration.

The 1974 California model is equipped with air injection plus a number of component modifications, including a reshaped piston crown which raises the combustion chamber surface-to-volume ratio from 7.5 to 8 in^{-1}, a higher compression ratio and slightly different valve timing and valve

TABLE 5-24. ENGINE SPECIFICATIONS: TOYOTA 96.9-CID ENGINE

Engine Parameter	Model Year							
	1976		1975		1974		1972	
	49 States	California	49 States	California	49 States	California	49 States	California
Type	2 T-C	2 T-C	2 T-C	2 T-C	2 T-C, EM	2 T-C, AI	2 T-C	
Bore, in.	3.25		3.25		3.25		3.25	
Stroke, in.	2.76		2.76		2.76		2.76	
Displacement, cu in.	96.9		96.9		96.9		96.9	
Surface/Volume, 1/in.	8		8		7.5	8	7.5	
Compression Ratio	9.0		9.0		8.5	9.0	8.5	
Cylinder Head Type	OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	75 at 5800	73 at 5800	75 at 5800	73 at 5800	88 at 6000		88 at 6000	
Torque, ft-lb, at Engine Speed, rpm	83 at 3800		83 at 3800		91.3 at 3800		91.3 at 3800	
Exhaust System Type	Single		Single		Single		Single	
Combustion Chamber Configuration	Hemisphere		Hemisphere		Hemisphere		Hemisphere	
Intake Valve Diameter, in.	1.61		1.61		1.61		1.61	
Intake Valve Lift, in.	0.34		0.34		0.34		0.34	
Exhaust Valve Diameter, in.	1.32		1.32		1.32		1.32	
Exhaust Valve Lift, in.	0.35		0.35		0.34		0.34	
Intake Valve Opens, deg BTC	16		16		16		16	
Intake Valve Closes, deg ABC	54		54		54		54	
Intake Valve Duration, deg	250		250		250		250	
Exhaust Valve Opens, deg BBC	56		56		56	58	58	
Exhaust Valve Closes, deg ATC	20		20		12	20	12	
Exhaust Valve Duration, deg	256		256		248	258	248	
Valve Overlap, deg	36		36		28	36	28	
Distributor Type	Breaker point or Breakerless		Breaker point or Breakerless		Breaker point		Breaker point	
Basic Ignition Advance, deg BTC	10		10		5	10	5	
Idle Speed, rpm[a]	930		850		800 (A) 750 (M)	850	650 (A) 750 (M)	
Fast Idle Speed, rpm	3000	2700	3000	2700	2700		-	
Fuel System Type	2V downdraft		2V downdraft		2V downdraft		2V downdraft	
Fuel Metering Method	-		-		-		-	
Enrichment Method	Power valve; acceleration pump		Power valve; acceleration pump		Power valve		Power valve	
Choke Type	Automatic; electrically heated		Automatic; electrically heated		Automatic, heated		Automatic, heated	
Carburetor Venturi Diameter, in.	0.91 (1V) 1.06 (2V)		0.91 (1V) 1.06 (2V)		0.91 (1V) 1.06 (2V)		-	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	129 at 2.36		129 at 2.36		131 at 2.36		-	
Emission Control Systems	AIR EVAP PCV	AIR CAT EVAP PCV	AIR EVAP PCV	AIR CAT EVAP PCV	EVAP PCV	AIR EVAP PCV	EVAP PCV	
Emission Control Devices	Deceleration device (throttle positioner)	TCS	Deceleration device (throttle positioner)	TCS	Deceleration device (throttle positioner; mixture control)[b] TCS		Deceleration device (throttle positioner; mixture control) TCS	

[a] A = automatic transmission; M = manual transmission

[b] 49-states vehicles only

TABLE 5-25. ENGINE SPECIFICATIONS: TOYOTA 133.6-CID ENGINE

Engine Parameter	Model Year			
	1976		1975	
	49 States	California	49 States	California
No. of Cylinders	4		4	
Bore, in.	3.48		3.48	
Stroke, in.	3.50		3.50	
Displacement, cu in.	133.6		133.6	
Surface/Volume, 1/in.	7.75		7.75	
Compression Ratio	8.4		8.4	
Cylinder Head Type	OHV		OHV	
Advertised HP at Engine Speed, rpm	96 at 4800	90 at 4800	96 at 4800	90 at 4800
Torque, ft-lb, at Engine Speed, rpm	120 at 2800		120 at 2800	
Exhaust System Type	Single		Single	
Combustion Chamber Configuration	Hemisphere		Hemisphere	
Intake Valve Diameter, in.	1.69		1.69	
Intake Valve Lift, in.	0.40		0.40	
Exhaust Valve Diameter, in.	1.42		1.42	
Exhaust Valve Lift, in.	0.40		0.40	
Intake Valve Opens, deg BTC	18		18	
Intake Valve Closes, deg ABC	58		58	
Intake Valve Duration, deg	256		256	
Exhaust Valve Opens, deg BBC	58		58	
Exhaust Valve Closes, deg ATC	18		18	
Exhaust Valve Duration, deg	256		256	
Valve Overlap, deg	36		36	
Distributor Type	Breaker point; transistorized		Breaker point; transistorized	
Basic Ignition Advance, deg BTC	8		8	
Idle Speed, rpm	850		850	
Fast Idle Speed, rpm	2400		2400	
Fuel System Type	2V downdraft		2V downdraft	
Fuel Metering Method				
Enrichment Method	Power valve		Power valve	
Choke Type	Automatic		Automatic	
Carburetor Venturi Diameter, in.	0.91 (1V) 1.18 (2V)		0.91 (1V) 1.18 (2V)	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	165 at 2.0		165 at 2.0	
Emission Control Systems	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV	AIR EGR EVAP PCV	AIR CAT EGR EVAP PCV
Emission Control Devices	Throttle positioner TCS		Throttle positioner TCS	

overlap. The 1975 and 1976 California and 49-states engines are similar to the 1974 California model, except for the transmission-controlled spark (TCS) which is not used in the 49-states calibrations. Improved valve materials (silchrom intake valve and stellite faced exhaust valves) and valve stem seals are used in 1976. The combustion chamber is of the hemispherical type which is known for its good efficiency and low HC emissions.

The 133.6-CID engine has similar design features, as shown in Tables 5-24 and 5-25. Both engines are equipped with conventional emission control systems and devices, which are listed in the tables and are described in the following subsections.

5.9.3 Toyota 96.9-CID Engine

5.9.3.1 Intake System

The 1975 and 1976 model 96.9-CID engines certified for 49-states and California applications are equipped with both intake manifold and air cleaner heating. The intake manifold is heated by the coolant which flows from the cylinder head through the intake manifold to the thermostat.

The air cleaner heating system consists of an intake manifold vacuum-operated air control valve and a bimetallic thermo-valve. The exhaust manifold serves as the air heater. The admission of heated air is controlled by the air control valve, whereas the vacuum admitted to the air control valve diaphragm is controlled by the thermo-valve. At low air temperatures, the thermo-valve is closed, and the intake manifold vacuum acting on the air control valve diaphragm opens the valve, which then admits hot air to the air cleaner and closes off the admission of cold air. The valve remains open until the sensed air temperature reaches 90°F. As the temperature continues to increase, the thermo-valve starts to open gradually relieving the vacuum in the air control valve diaphragm chamber and causing progressive closing of the valve. When the sensed air temperature reaches 108°F, the thermo-valve is fully open, and the air control valve is fully closed, shutting off the admission of hot air.

5.9.3.2 Carburetor

5.9.3.2.1 Design Features

The basic design of the carburetor, manufactured by Aisan, has not been changed since 1972. However, a number of modifications have been incorporated over the years to improve the mixture preparation and cold start characteristics of the engine.

5.9.3.2.2 Control Devices

As indicated in Table 5-24, two deceleration devices, the throttle positioning (TP) system and the mixture control (MC) system have been employed since 1972 to aid in the control of HC and CO emissions during deceleration. For vehicle speeds above 10 mph during acceleration, a speed sensor located in the TP system sends a signal to a computer, causing the opening of a vacuum switching valve and allowing atmospheric pressure to enter the TP diaphragm chamber, which is then positioned by a spring (Fig. 5-28). If under these conditions the accelerator pedal is released, the throttle valve lever strikes the TP and remains slightly open. Conversely, when the vehicle speed decreases below 15 mph, a low-speed signal to the computer causes closing of the vacuum switching valve, which then admits intake manifold vacuum into the TP diaphragm chamber, allowing the throttle valve to return to the idle position.

The MC system, shown in Fig. 5-29, becomes operative during periods of sudden deceleration admitting supplementary air into the intake manifold during a transient period, thus leaning the air/fuel mixture and reducing the formation of HC and CO. The system is activated for vehicle speeds above 41 mph, becoming deactivated during deceleration at 31 mph. At idle and low vehicle speeds, the vacuum switching valve (VSV) of the system remains closed, cutting off intake manifold vacuum to the MC diaphragm. As a result, the pressure on both sides equalizes by means of a small orifice, and the MC remains closed. At medium and high vehicle speeds (high load), the vacuum switching valve opens, admitting intake manifold vacuum to the MC diaphragm chamber. However, the MC valve remains closed at that condition because intake manifold vacuum is low and the pressure on both sides of the diaphragm has time to equalize. During sudden deceleration (high vacuum) the MC opens, momentarily admitting fresh air into the intake manifold until the pressure on both sides of the diaphragm equalizes through the orifice, closing the MC. The MC system is discontinued in 1974 on California vehicles and in 1975 on 49-states vehicles. It has been replaced by the use of leaner and more closely controlled air/fuel ratios at idle and low speeds.

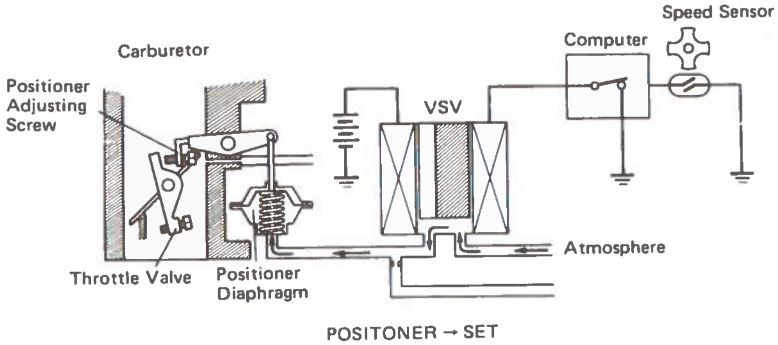


FIGURE 5-28. TP SYSTEM: TOYOTA 96.9-CID ENGINE

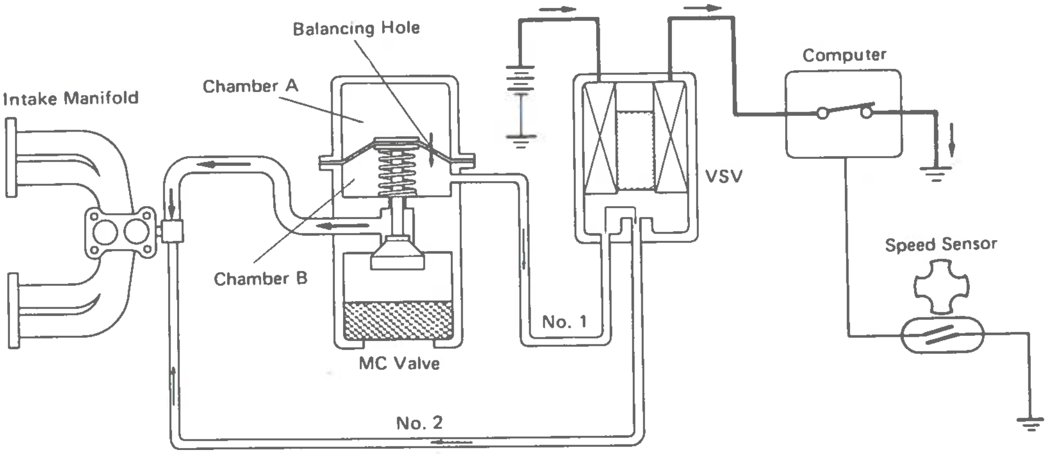


FIGURE 5-29. MC SYSTEM: TOYOTA 96.9-CID ENGINE

In 1975, an auxiliary acceleration pump (AAP) is used which is designed to supplement the piston-type throttle-linked acceleration pump and to provide a richer mixture during cold start. When the engine is cold, the thermal vacuum switching valve is open, allowing vacuum to pull on the diaphragm of the AAP and to fill the chamber with fuel. During subsequent acceleration the vacuum declines, and the fuel stored in the AAP is then discharged into the carburetor by the spring action. Conversely, for engine coolant temperatures above about 158°F during warmup and below 113°F during cooldown, the thermal valve is closed, blocking the vacuum passage to the pump diaphragm chamber and rendering the AAP inoperative.

In 1976 the speed limits of the TP system are reduced to 7 mph and 11 mph, respectively.

5.9.3.2.3 Cold Start Control

For improved cold start characteristics combined with HC and CO emission control, all 1972-1976 carburetors are equipped with a heated automatic choke system. In 1974 and earlier model years, the bimetallic coil controlling the choke opening is heated by air passing through an exhaust manifold stove, with the choke remaining fully closed at air temperatures below 77°F. To prevent over-rich mixtures during engine startup, the choke is kept slightly open by means of an intake manifold vacuum-operated piston.

In the 1975 and 1976 model carburetor, the bimetallic spring controlling the choke opening is heated electrically by means of a heating coil. The coil is activated when the engine is started. To prevent over-rich mixtures during the cold start phase, a choke breaker diaphragm is used which operates in a manner similar to the piston used in the 1974 system.

The 1975 and 1976 California vehicles utilize a choke opener (COP) system which is designed to reduce cold start HC and CO emissions by minimizing the choke period. In this arrangement, the choke opening is controlled by the choke opener diaphragm which is connected to intake manifold vacuum via the VSV. The VSV receives signals from the vehicle speed sensor and the coolant temperature sensor. For vehicle speeds above 4 mph during acceleration and above 11 mph during deceleration and for coolant temperatures between 55 and 212°F, the VSV is energized, and the choke is opened.

5.9.3.2.4 Carburetor Calibration

The carburetor calibration data provided by Toyota are listed in Table 5-26, showing the air/fuel ratios at a number of discrete air flow settings. Relative to 1972, richer air/fuel mixtures are used in 1974, particularly in the California vehicles. This change is attributed to the use of an air injection system for HC and CO control in 1974 and the imposition of more stringent NO_x standards in California. The air/fuel ratio of the 49-states vehicles with automatic transmission has remained nearly constant between 1974 and 1976, except for the moderate 1975/76 increase shown in Table 5-26 at the 3 lb/min part-load condition. Conversely, the mixture of the 1975 and 1976 California vehicles and the 49-states vehicles with manual transmission has been enriched, relative to 1974, to improve the HC and CO conversion effectiveness of the air injection system and the catalyst.

The calibration tolerance band has remained near ±5 percent since 1974, except for the idle and low load conditions in 1974, which have a tolerance band of about ±7 percent for the 49-states configuration and about ±6 percent for California. The impact of the observed air/fuel ratio variations on fuel economy and emissions is discussed in Section 5.9.3.8.

5.9.3.3 Ignition System

5.9.3.3.1 Design Features

As shown in Table 5-24, the conventional breaker-point ignition system has been replaced, in 1975, by a transistorized breaker-point system. The transistorized system operates with lower current through the breaker-points, hence reducing breaker-point wear while providing higher primary voltage and higher spark intensity. A dual breaker-point system, shown in Figure 5-30, is available as optional equipment in 1975 model 49-states engines. For coolant temperatures below 95°F, the thermal sensor switch is closed, and the control relay in the main breaker-point circuit is open. In this case, spark control is maintained by the second breaker-point set, which has a 10-deg advance relative to the main breaker-points. Conversely, for coolant temperatures above 95°F, the thermal switch opens, and normal spark control is then provided by the main breaker-point unit.

TABLE 5-26. CERTIFICATION CALIBRATION DATA: TOYOTA 96.9-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter	Model Year and Certification Standard																	
	1976 49 States			1976 California			1975 49 States		1975 California			1974 49 States		1974 California		1973		1972
Transmission Type	A	M4	M5	A	M4	M5	M4	M5	A	M4	M5	A	M4	A	M4	A	M4	-
Vehicle Inertia Weight, lb	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2250	2250	2500	2250	2250	2250	-
Rear Axle Ratio	4.10	4.10	4.30	4.10	4.10	4.10	4.10	4.30	4.10	4.10	4.30	3.90	4.11	4.10	3.91	4.11	3.90	-
Catalyst	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No
Carburetor Calibration, A/F																		
0.32-lb/min air flow	11.2	11.3	11.3	11.2	11.2	11.2	11.2	11.3	11.2	11.2	11.2	-	-	-	-	-	-	13.5
0.62-lb/min air flow	12.4	11.3	11.3	10.8	10.8	10.8	12.4	11.3	10.8	10.8	10.8	12.8	12.8	11.9	11.9	-	-	13.9
0.92-lb/min air flow	14.7	13.2	13.2	12.6	12.6	12.6	14.7	13.2	12.6	12.6	12.6	14.6	14.6	13.2	13.2	-	-	15.3
3.00-lb/min air flow	16.6	16.1	16.1	15.5	15.5	15.5	16.6	16.1	15.5	15.5	15.5	15.8	15.8	15.3	15.3	-	-	16.8
WOT at Max.: 9.00-lb/min air flow	14.5	14.2	14.2	14.2	14.2	14.2	14.5	14.2	14.2	14.2	14.2	14.5	14.5	14.8	14.8	-	-	14.6
Basic Timing, crankshaft deg BTC	10	10	10	10	10	10	10	10	10	10	10	5	5	10	10	-	-	5
Centrifugal Advance, crankshaft deg																		
1000 rpm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	0
1500 rpm	5	5	5	4	4	4	0	0	4	4	4	6	8	4	4	-	-	8.5
2000 rpm	10	10	10	7	7	7	6	6	7	7	7	12	17	7	7	-	-	16
3000 rpm	16.5	16.5	16.5	14	14	14	16	16	14	14	14	22	23.5	14	14	-	-	23
4000 rpm	20.5	20.5	20.5	18	18	18	18	18	18	18	18	28	29.5	19	19	-	-	29
5000 rpm	24	24	24	24	24	24	18	18	24	24	24	33	33	24	24	-	-	32
Vacuum Advance, crankshaft deg																		
3.5 in. Hg	0	0	0	0	0	0	2	2	0	0	0	3	2	0	0	-	-	1
4 in. Hg	2	2	2	2	2	2	5	5	2	2	2	6	4	2	2	-	-	4
5 in. Hg	6	6	6	6	6	6	8	8	6	6	6	10.5	10	6	6	-	-	11
6 in. Hg	8	8	8	8	8	8	9	9	8	8	8	14	14	8	8	-	-	16
8 in. Hg	12	12	12	12	12	12	12	12	12	12	12	14	14	11	11	-	-	16
10 in. Hg	14	14	14	14	14	14	15	15	14	14	14	14	14	14	14	-	-	16
12 in. Hg	14	14	14	14	14	14	17	17	14	14	14	14	14	14	14	-	-	16
15 in. Hg	14	14	14	14	14	14	20	20	14	14	14	14	14	14	14	-	-	16
Fuel Economy, mpg[a]																		
City	24	23	22	22	20	20	21	21	21	20	18	20.8^b	22.6^b	19.6^b	18.8^b	22.6^b	20.8^b	-
Highway	32	34	37	27	33	36	35	33	25	30	31	-	-	-	-	-	-	-
Exhaust Emissions, g/m																		
HC	1.3	1.2	1.1	0.4	0.5	0.3	1.4	1.4	0.2	0.4	0.5	2.3^b	2.5^b	1.2^b	1.8^b	2.5^b	2.3^b	-
CO	9	11	12	6	4	4	10	11	3	3	4.5	28^b	26^b	21^b	20^b	25^b	27^b	-
NO_x	2.4	2.2	2.7	1.5	1.9	1.0	2.4	3.1	1.4	1.5	1.6	1.8^b	1.4^b	1.7^b	1.5^b	1.4^b	1.7^b	-

[a] 1975 FTP

[b] 1972 FTP

[a] 1975 FTP [b] 1972 FTP

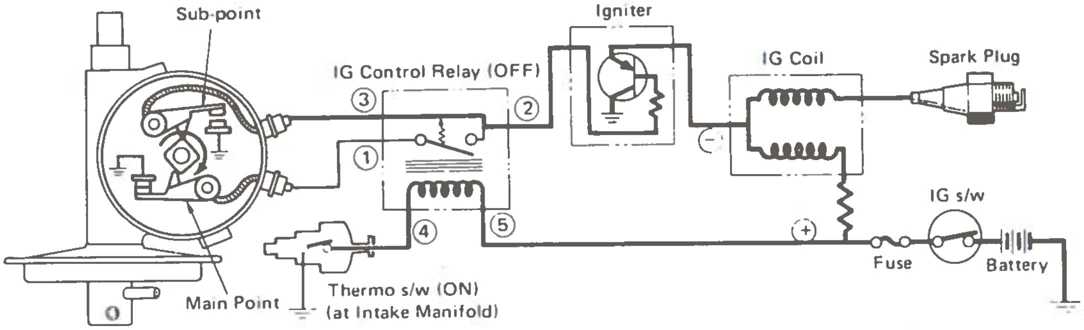


FIGURE 5-30. TOYOTA DUAL BREAKER-POINT IGNITION SYSTEM

5.9.3.3.2 Spark Timing Control Devices

All 1972-1974 model 96.9-CID engines are equipped with a TCS system, consisting of a speed sensor, a coolant temperature sensor, a vacuum switching valve, and a computer. This system is designed to provide NO_x and HC control by negating vacuum advance under certain operating conditions. In all 1972 vehicles and in the 1974 model 49-states calibration, TCS is activated for coolant temperatures between 140 and 221°F and vehicle speeds below 41 mph during acceleration and below 31 mph during deceleration. This causes cancellation of the vacuum advance by admitting atmospheric pressure to the distributor diaphragm chamber. For all engine operating conditions outside these limits, the ignition advance system functions normally. The corresponding speed settings for the 1974 California vehicles are 41 and 16 mph for automatic transmissions and 65 and 24 mph for manual transmissions.

The 1975 and 1976 model 49-states engines are equipped with a spark advance delay system for NO_x and HC control, which consists of a thermo-vacuum switch valve (TVSV), sensing engine coolant temperature, an orifice and check valve unit located in the main vacuum line between carburetor port and distributor, and a second vacuum line passing through the TVSV. For coolant temperatures above 140°F (increasing) or 95°F (decreasing), the TVSV is closed and the vacuum signal to the distributor is transmitted through the main line. As the carburetor throttle is opened from the closed position during periods of acceleration, the check valve in the main line closes, and the transmission of the vacuum signal is delayed through the small orifice installed in a parallel arrangement with the check valve. Conversely, for low vacuum signals (high loads), the check valve opens, and the vacuum advance unit is operative without delay. Under cold engine conditions, the TVSV is open, and vacuum advance is provided through the secondary line without delay.

The 1976 model 49-states engine has an optional dual vacuum advance system which is designed to improve the cold start operating characteristics of the engine by providing additional spark advance for coolant temperatures up to 95°F.

The 1975 and 1976 California vehicles are equipped with a TCS system which is similar to the 1974 system. While the coolant temperature control limits are identical to the 1974 settings, the speed control points for automatic transmission installations have been changed to 65 mph and 10 mph. In the manual transmission case, the speed sensor has been replaced by a gear selection sensor which engages TCS in the lower three gears.

5.9.3.3.3 Spark Advance Schedules

The centrifugal and vacuum advance schedules of the Toyota 1972 and 1974-1976 model 96.9-CID engine equipped vehicles are listed in Table 5-26 at discrete engine speed and carburetor port vacuum settings. Also shown is the basic advance in terms of engine crankshaft deg before piston top center. The centrifugal advance including basic timing of the 1974 model 49-states vehicles with automatic transmission and the 1974 California vehicles with manual or automatic transmission are retarded relative to 1972, reflecting the more stringent NO_x regulations in 1974. Conversely, the centrifugal advance of the 1974 model 49-states vehicles with manual transmission has remained nearly unchanged between 1972 and 1974. While the centrifugal advance of the 49-states vehicles shows an additional decline in 1975, followed by a recovery in 1976, the centrifugal advance schedules of the 1975 and 1976 catalyst equipped California vehicles are practically identical to the 1974 settings.

Relative to 1972, the vacuum advance of the 1974 model 49-states vehicles is slightly retarded, except at low vacuum levels where the advance has increased slightly. This is followed by further declines in the low vacuum regime in 1975 and 1976, accompanied by a small increase in the advance at high vacuum levels in 1975. Conversely, the vacuum advance of the California vehicles has remained unchanged between 1974 and 1976.

While the spark advance schedule modifications implemented by Toyota over the past several years are moderate, it should be noted that a number of spark control devices have been incorporated in various model years to delay the vacuum advance over much of the Federal Driving Cycle.

5.9.3.4 Exhaust Gas Recirculation

EGR is not used in the Toyota 96.9-CID engine, and NO_x control is achieved primarily by means of spark retard. In addition, valve overlap has been increased in the 1974 California vehicles to provide more internal EGR for NO_x control. The increased valve overlap is retained in all 1975 and 1976 engines.

5.9.3.5 Secondary Air Injection

Secondary air injection, in conjunction with spark retard, represents the principal HC and CO emission control technique employed by Toyota in its 1974-1976 model 96.9-CID engines certified for use in California as well as in the 1975 and 1976 model 49-states engines.

The secondary air system used in 1974 consists of a vane-type pump of 9.89 CID/sec, pressure relief valve, ABPV, check valve, air injection manifold, and associated piping. The ABPV is operated by means of a diaphragm which has a small orifice to balance the pressure on both sides of the diaphragm. The bottom side of the diaphragm is connected to intake manifold vacuum. In all engine operating modes, except deceleration, the air supplied by the pump passes through the ABPV and the check valve before being injected upstream of each exhaust valve. During deceleration, the rapid increase in intake manifold vacuum unbalances the air bypass diaphragm. As a result, the air manifold passage closes, and the secondary air is discharged to atmosphere to prevent backfire in the exhaust system. After a short time, the pressure across the diaphragm is balanced through the orifice, and air injection is resumed. The check valve prevents hot exhaust gases from entering the pump in case of drive belt or relief valve failure. The pump discharge pressure is 2.1 psi minimum at an engine speed of 1950 rpm, and the relief valve setting is between 2.8 and 5 psi.

The secondary air system used in 1975 and 1976 is similar to the 1974 system except for minor modifications. These include the addition of an air switching valve (ASV) in the 1975 and 1976 model 49-states vehicles, the use of a VSV in the 1975 and 1976 California engines, and slight adjustments in the air pump discharge pressure and relief valve settings.

The function of the ASV is combined with that of the relief valve. Near open throttle, the ASV closes the air passage to the exhaust manifold to prevent overheating of the exhaust system by redirecting the secondary air into the air cleaner. The function of the ASV is delayed by an auxiliary valve (vacuum transmitting valve), which slowly bleeds air through a small orifice into the ASV diaphragm chamber. The VSV is designed to provide on-off control of air injection. In the on position, manifold vacuum is admitted to the ASV diaphragm chamber. Conversely, in the off position, ambient pressure is provided through a passage in the VSV, lifting the ASV piston and rerouting the secondary air to the air cleaner. The operation of the VSV is controlled by the central computer as a function of vehicle speed, coolant temperature, catalyst temperature, and compartment floor temperature. Air injection is used for vehicle speeds below 65 mph, coolant temperatures between 55 and 220°F, catalyst temperatures below 1380°F, and floor temperatures below 275°F. In 1976, the VSV system is simplified by limiting the control parameters to engine coolant temperature.

5.9.3.6 Catalytic Converter

For control of HC and CO, a catalytic converter, operating in conjunction with secondary air injection, is used in the 1975 and 1976 California vehicles. This converter, which is located upstream of the muffler, is 13.7 inches long, 7.2 inches wide, and 3.2 inches high. The active catalyst material consists of a mixture of platinum and palladium deposited on small alumina pellets. The system includes a warning light and a buzzer, both of which are activated when the catalyst temperature reaches a nominal temperature of about 1380°F.

5.9.3.7 Crankcase and Evaporative Emission Control

All Toyota engines are equipped with a PCV system and an evaporative emission control system. Both systems are functionally identical to the configurations described in Section 3. The operation of the evaporative system is controlled by a vacuum switching valve which permits purging of the charcoal canister at vehicle speeds above about 15 mph. Conversely, at lower speeds or when the engine is turned off, the fuel vapors from the fuel tank are stored temporarily in the charcoal canister.

5.9.3.8 Fuel Economy and Emissions

The city and highway fuel economy of selected 1973-1976 certification vehicles with manual and automatic transmission are listed in Table 5-26. These data as well as the data for the remaining certification vehicles not listed have been normalized to a common inertia weight of 2500 pounds and a common axle ratio of 4.1, using the method previously discussed in Section 3. The normalized average city fuel economy of the vehicles with manual transmission is presented in Figure 5-31, and the average emissions are shown in Figure 5-32 as a function of model year. As indicated in Figure 5-31, the fuel economy of the 49-states vehicles decreases by about 7 percent between 1974 and 1975, followed by a complete recovery in 1976. These trends reflect the previously noted adjustments in the centrifugal spark advance implemented between 1974 and 1976. Conversely, the fuel economy of the California vehicles remains nearly unchanged between 1974 and 1976 reflecting the constant spark advance schedules for this time period. Similar trends are obtained for the vehicles with automatic transmission. (Refs. 5-8 through 5-11, 5-13, and 5-20).

While the lower fuel economy of the 1975 and 1976 California vehicles can be attributed to the use of TCS, which negates the vacuum advance over much of the driving cycle, the large fuel economy difference observed between the 1974 California and 49-states vehicles is difficult to rationalize,

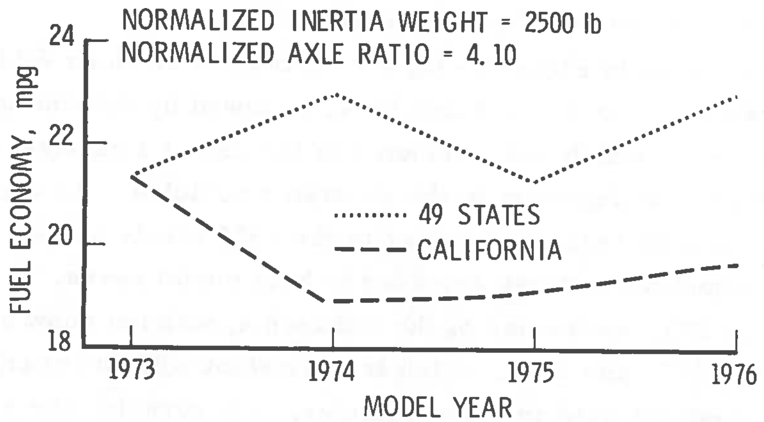


FIGURE 5-31. NORMALIZED AVERAGE CITY FUEL ECONOMY: TOYOTA 96.9-CID ENGINE WITH MANUAL TRANSMISSION

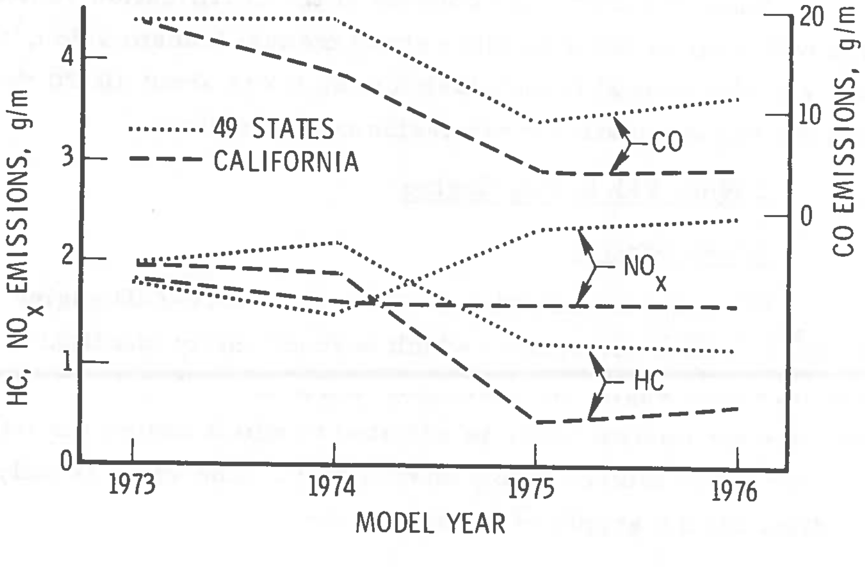


FIGURE 5-32. AVERAGE EXHAUST EMISSIONS: TOYOTA 96.9-CID ENGINE WITH MANUAL TRANSMISSION

although lower air/fuel ratio and mid-speed spark advance settings are employed in the California vehicles. In addition, higher valve overlap is used in California, which increases the amount of internal EGR at the expense of a small loss in fuel economy. Considering the small data sample available in 1974, at least part of the observed fuel economy difference might be caused by normal test-to-test and vehicle-to-vehicle variabilities.

As shown in Figure 5-32, the emissions of these vehicles remains nearly constant between 1973 and 1974, followed by substantial HC and CO reductions in 1975, which are attributed to the use of a catalyst in California and secondary air injection in the 49-states vehicles. As expected, the HC and CO emissions in 1976 are similar to the 1975 levels because the same catalyst and air injection systems are used in both model years.

The NO_x emissions of the California vehicles show only small variations between 1974 and 1976, which is consistent with the nearly constant spark advance schedules used in these vehicles. Conversely, the substantial rise in NO_x observed in the 1975 model 49-states vehicles is considered to be due primarily to the elimination of TCS in these vehicles. Other contributing factors include small variations in the air/fuel ratio and spark advance settings implemented in 1975.

While the city fuel economy of the certification vehicles show no clear trend with regard to automatic versus manual transmission, the highway fuel economy of the manual transmission vehicles is about 10-20 percent higher than for the automatic transmission configurations.

5.9.4 Toyota 133.6-CID Engine

5.9.4.1 Intake System

Since its introduction in 1975, the 133.6-CID engine has been equipped with an intake air system which is functionally identical to the unit used in the 96.9-CID engine as described in Section 5.9.3.1. In the 133.6-CID engine, the air control valve is adjusted to admit heated air into the air cleaner for air temperatures below about 100°F. The valve is fully closed at 106°F, shutting off the supply of preheated air.

5.9.4.2 Carburetor

5.9.4.2.1 Design Features

The carburetor used in the 1975 and 1976 model 133.6-CID engines is similar to the 2V downdraft unit employed in the 96.9-CID engine, except for minor modifications in the size of the venturi's and fuel jets.

5.9.4.2.2 Control Devices

For control of HC and CO emissions, the carburetor is equipped with a deceleration control device consisting of a throttle positioning system. This system is functionally identical to the system used in the 96.9-CID engine, except that the control speed points are set at 13 mph during acceleration and 17 mph during deceleration.

For mixture enrichment during acceleration, an AAP is used which is similar to the unit described in Section 5.9.3.2.2. The AAP is operative for engine coolant temperatures below 122°F while accelerating and below 77°F while decelerating. The discharge flow of the AAP varies linearly with intake manifold vacuum, reaching a maximum flow of 0.15 cu in per cycle.

The 1976 model 49-states engines incorporate a hot idle compensator which is designed to offset mixture enrichment caused by variations in air density and by fuel vapors generated during hot engine operation. The compensator consists of a valve which is controlled by a bimetallic strip. Normally, the compensator valve is held closed by the tension of the bimetallic strip and by intake vacuum. However, as the engine heats up, the bimetallic strip opens the compensator, permitting additional air to be drawn into the carburetor air passage and providing leaner air/fuel mixtures.

5.9.4.2.3 Cold Start Control

The carburetor used in both 49-states and California installations incorporates an automatic choke heated by engine coolant, which aids in the control of HC and CO by limiting the choke action time during engine cold start. A COP is used in this carburetor, which is similar to the configuration employed in the 96.9-CID engine although its mechanization is somewhat different. When the VSV is energized, the diaphragm chamber of the choke opener is connected to intake manifold vacuum via a vacuum transmitting valve (VTV) which opens the choke. The VTV delays closing of the choke as intake manifold vacuum decreases rapidly during vehicle acceleration. In the 49-states vehicles, the VSV is open for coolant temperatures between 55 and 221°F and vehicle speeds below 65 mph (accelerating) or 20 mph (decelerating). In addition to these controls, the California vehicles are equipped with catalysts and compartment floor temperature sensors which render the choke inoperative for temperatures above about 1380 and 275°F, respectively.

5.9.4.2.4 Carburetor Calibration

Carburetor calibration data for the Toyota 133.9-CID engine are listed in Table 5-27 in terms of air/fuel mixture ratio at four discrete part-throttle settings and at WOT. As indicated, the 49-states vehicles with automatic transmission are calibrated leaner than the manual transmission vehicles, except at low loads where the differences are negligible. Similar trends are observed for the 1976 California vehicles. Conversely, the 1975 California air/fuel ratio settings are identical for both manual and automatic transmissions. In general, richer mixtures are used in the California vehicles, reflecting the more stringent California emission standards.

The air/fuel ratio tolerance bands remain unchanged at ±5 percent in 1975 and 1976.

5.9.4.3 Ignition System

5.9.4.3.1 Design Features

The ignition system used in the 133.6-CID engine is functionally identical to the unit described in Section 5.9.3.3 for the 96.9-CID engine and consists of a transistorized, single breaker-point arrangement with centrifugal and vacuum advance.

5.9.4.3.2 Spark Timing Control Devices

In addition to the conventional centrifugal and vacuum spark control, all 133.6-CID engines employ a TCS advance mechanism to assist in the control of NO_x and HC. The TCS unit is controlled by vehicle speed and engine coolant temperature in a manner previously described in Section 5.9.3.3.2. In this engine, TCS is inoperative during engine warmup (engine coolant temperature below 122°F) and for vehicle speeds above 41 mph during acceleration and 21 mph during deceleration.

TABLE 5-27. CERTIFICATION CALIBRATION DATA: TOYOTA 133.6-CID ENGINE WITH AUTOMATIC AND MANUAL TRANSMISSION

Engine/Vehicle Parameter[a]	Model Year and Certification Standard										
	1976 49 States			1976 California			1975 49 States			1975 California	
Vehicle Model	Ce[b]	Co[c]	Ce[b]	Ce[b]	Co[c]	Ce[b]	Co[c]	Co[c]	Co[c]	Co[c]	Co[c]
Transmission Type	A	M4	M5	A	M4	M5	A	M4	M5	A	M4
Inertia Weight, lb	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Rear Axle Ratio	3.91	3.73	3.73	3.91	3.73	3.73	3.91	3.91	3.73	3.91	-
Catalyst	No	No	No	Yes	Yes	Yes	No	No	No	Yes	Yes
Carburetor Calibration, A/F											
Idle: 0.5-lb/min air flow	11.6	11.5	11.5	11.5	11.5	11.5	11.6	11.5	11.5	11.5	11.5
0.83-lb/min air flow	12.4	12.3	12.3	12.3	11.9	11.9	12.4	12.3	12.3	12.3	12.3
Off Idle: 1.40-lb/min air flow	16.0	15.4	15.4	15.3	13.9	13.9	16.0	15.4	15.4	15.4	15.4
Part Throttle: 3.70-lb/min air flow	15.7	15.3	15.3	15.3	14.5	14.5	15.7	15.3	15.3	15.3	15.3
WOT at Max.: 10.5-lb/min air flow	15.1	14.9	14.9	14.9	14.8	14.8	15.1	14.9	14.9	14.9	14.9
Basic Timing, crankshaft deg BTC	8	8	8	8	8	8	8	8	8	8	8
Centrifugal Advance, crankshaft deg											
1000 rpm	0	0	0	0	0	0	0	0	0	0	0
1500 rpm	4	4	4	4	4	4	5	5	5	4	4
2000 rpm	10	10	10	10	10	10	11	11	11	10	10
3000 rpm	14	14	14	14	14	14	16.5	16.5	16.5	18	18
4000 rpm	16.5	16.5	16.5	16.5	16.5	16.5	24	24	24	22	22
5000 rpm	20.5	20.5	20.5	20.5	20.5	20.5	31	31	31	25	25
Vacuum Advance, crankshaft deg											
4 in. Hg	0	0	0	0	0	0	4	4	4	0	0
5 in. Hg	3	3	3	3	3	3	11	11	11	3	3
6 in. Hg	7	7	7	7	7	7	14	14	14	6	6
8 in. Hg	13	13	13	13	13	13	17	17	17	12.5	12.5
10 in. Hg	16	16	16	16	16	16	20	20	20	16	16
12 in. Hg	20	20	20	20	20	20	20	20	20	20	20
15 in. Hg	20	20	20	20	20	20	20	20	20	20	20
Fuel Economy, mpg											
City	21	19	20	20	18	20	20	19	18	19	16
Highway	31	31	36	29	29	36	26	28	32	24	28
Exhaust Emissions, g/m											
HC	1.2	1.1	1.1	0.3	0.4	0.3	1.0	0.9	0.7	0.3	0.4
CO	9	13	13	3	4	4	10	10	9	4	3
NO_x	2.9	2.3	2.2	1.3	1.0	1.0	2.4	2.1	2.1	1.3	1.3

[a] EGR valve calibration shown in Figure 5-34.

[b] Celica

[c] Corona

5.9.4.3.3 Spark Advance Schedules

Basic timing and centrifugal and vacuum advance schedules for the Toyota 133.6-CID engine are listed in Table 5-27, showing spark advance in terms of crankshaft deg as a function of engine speed and carburetor port vacuum. In the low engine speed regime, the centrifugal advance of the California and 49-states vehicles remain essentially unchanged between 1975 and 1976. However, at higher speeds, the centrifugal advance is retarded in 1976 relative to 1975, particularly for the 49-states vehicles. Conversely, nearly identical vacuum spark advance schedules are used for all engines, except the 1975 model 49-states configurations, which use higher advance in the low vacuum regime. The effect of these variations on vehicle fuel economy and emissions is discussed in Section 5.9.4.9.

5.9.4.4 Exhaust Gas Recirculation

5.9.4.4.1 Design Features

Unlike the 96.9-CID engine, the Toyota 133.6-CID engine is equipped with an EGR system to aid in the control of NO_x. While the same basic system is used nationwide, the EGR flow rates of the California vehicles are higher than for the 49-states vehicles. The system which is shown schematically in Figure 5-33 consists of a vacuum port controlled EGR valve, an EGR cooler, and a control circuit. Exhaust gas taken from the exhaust manifold is drawn through the cooler (cooling medium is engine coolant) to the EGR valve, which is controlled by a VSV and by the central computer. Both coolant temperature and vehicle speed are used in the control of the VSV. In the 1975 system, the VSV is activated (open valve) for coolant temperatures between 55 and 221°F and for vehicle speeds below 65 mph during acceleration and below 45 mph during deceleration. Under these conditions, port vacuum is admitted to the EGR valve diaphragm chamber, lifting the valve off its seat and allowing flow of exhaust gases into the carburetor. The 1976 EGR system is operational for coolant temperatures above 55°F and vehicle speeds below 65 mph (acceleration) and 55 mph (deceleration).

The EGR system incorporates a warning light which comes on automatically at 25,000-mile intervals to indicate the need for EGR maintenance. The light stays on until the switch is reset during maintenance.

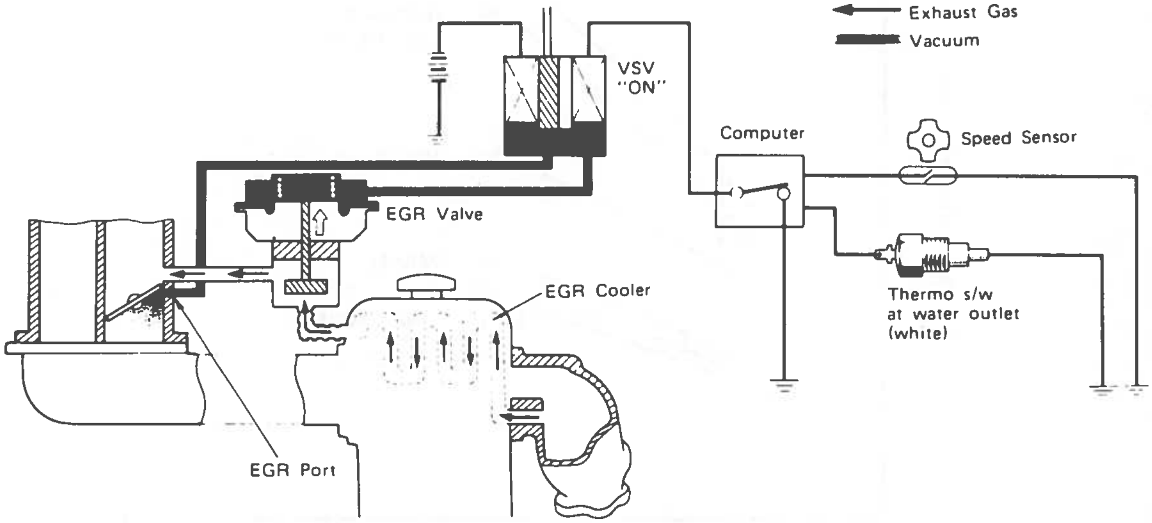


FIGURE 5-33. EGR SYSTEM: TOYOTA 133.6-CID ENGINE

5.9.4.4.2 EGR Valve Calibration

The available EGR valve calibration data are presented graphically in Figure 5-34, showing the EGR flow rate for the various calibration levels as a function of the valve differential pressure. While these data do not permit a precise determination of the EGR flow to engine flow rate ratio, they are useful for qualitative considerations. For example, the California vehicles use approximately twice as much EGR as the corresponding 49-states vehicles, which is reasonable considering the more stringent California NO_x regulations. While identical EGR flow calibrations are used in 1975 for manual and automatic transmission vehicles, the calibration is improved in 1976, permitting lower EGR rates for the vehicles with manual transmission.

5.9.4.5 Secondary Air Injection

As shown in Table 5-25, all 133.6-CID engines are equipped with a secondary air injection system which is functionally identical to the

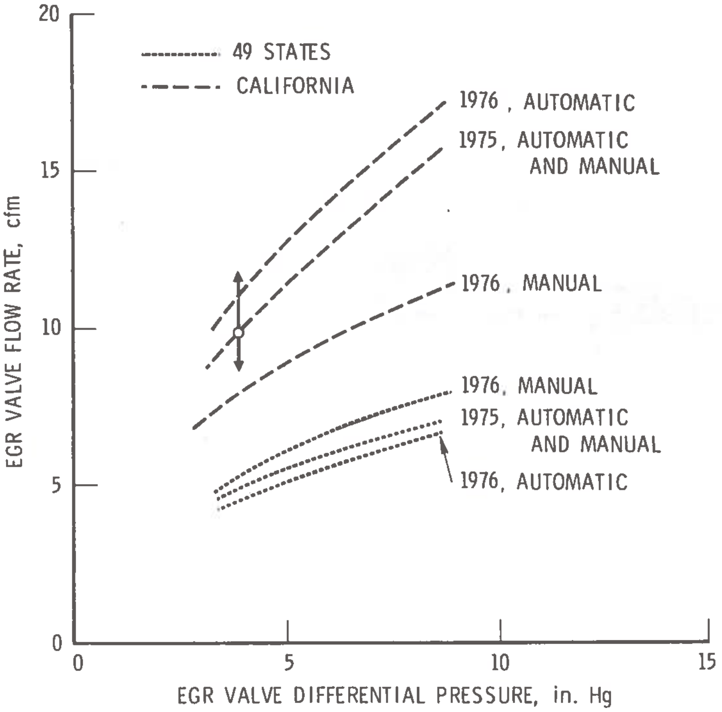


FIGURE 5-34. EGR VALVE CALIBRATION: TOYOTA 133.6-CID ENGINE

system used in the 96.9-CID engine. Air injection is controlled by coolant temperature and vehicle speed. In addition, the catalytic converter temperature is used as a control parameter in California vehicles. The temperature and vehicle speed control points used in 1975 are identical to the settings in the 96.9-CID engine. Conversely, in 1976, EGR is activated for coolant temperatures above 55°F (increasing temperatures) or 43°F (decreasing temperatures) and for vehicle speeds below 65 mph (acceleration) and 55 mph (deceleration).

5.9.4.6 Catalytic Converter

All 133.6-CID engine/vehicle configurations certified for use in California are fitted with a precious metal catalytic converter which is identical to the unit used in the 96.9-CID engine.

5.9.4.7 Crankcase and Evaporative Emission Control

The design and operating characteristics of the crankcase and evaporative emission control systems are identical to the systems used in the 96.9-CID engine.

5.9.4.8 Fuel Economy and Emissions

The city and highway fuel economy for selected certification vehicles is presented in Table 5-27. While two vehicles are generally used for certification, only the best fuel economy vehicle is listed in the table for each model year and calibration level. These data, as well as the data for the remaining certification vehicles not shown in the table have been normalized, using the procedure described in Section 3. As indicated in Figure 5-35, the normalized average city fuel economy of the 1976 model year vehicles shows an improvement relative to 1975, which is difficult to explain on the basis of the previously noted small variations in air/fuel ratio, spark timing, and EGR flow calibrations. However, the generally leaner mixtures employed in the vehicles with automatic transmission would tend to improve the fuel economy of these vehicles relative to the manual transmission configurations. The lower city fuel economy of the California vehicles is attributed to the higher EGR rates used in these vehicles to meet the more stringent California NO_x standard. Similar trends are observed for the highway cycle (Refs. 5-8 through 5-11).

Unlike most other engine/vehicle configurations, the city fuel economy of the vehicles with automatic transmission is better than for the manual transmission vehicles, whereas the opposite is observed for the highway fuel economy. Since the emission control system is identical for both configurations and no significant calibration changes could be identified, the observed trend in city fuel economy might be attributed to design improvements in the automatic transmission and/or better matching of the automatic transmission and engine system in the low-to-medium load and speed regimes. In general, the 4 and 5 speed manual transmissions give similar city fuel economy while the 5 speed transmission is superior over the highway cycle.

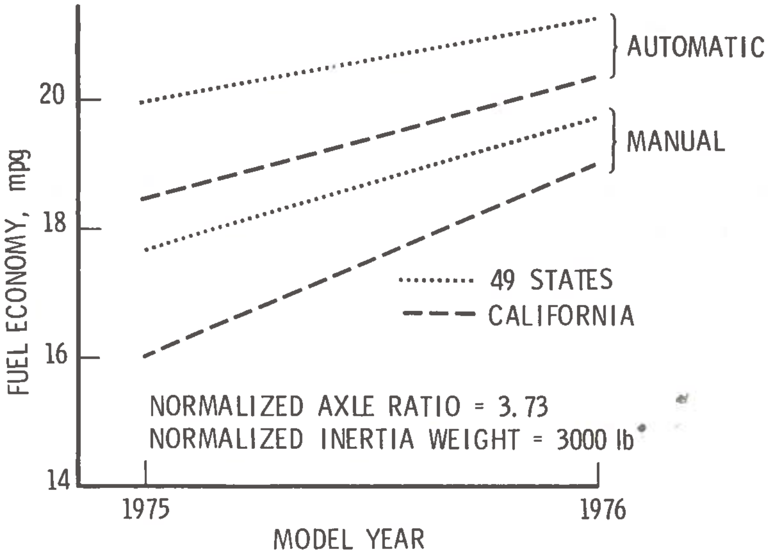


FIGURE 5-35. NORMALIZED AVERAGE CITY FUEL ECONOMY: TOYOTA 133.6-CID ENGINE

Except for a moderate increase in the average NO_x emission of the 49-states vehicles with automatic transmission in 1976, the emissions have remained nearly constant between 1975 and 1976, which is reasonable considering the small calibration variations.

5.10 VOLKSWAGEN

5.10.1 Engine/Vehicle Configurations

Two engines produced by VW have been selected to characterize its engine control practices. The first is an air-cooled, horizontally opposed, 4-cylinder, 96.7-CID unit. This engine is most often teamed with the VW Beetle but also is used in other VW vehicles. The Beetle is available as a sedan rated at 2250-pounds inertia weight or as a convertible rated at 2500-pounds. A manual four-speed and a semiautomatic transmission are offered in 1968, 1970, 1974, and 1975. In 1976, only the four-speed manual transmission is offered.

The second of the two engines selected is the powerplant used in the VW Dasher, Rabbit, and Scirocco. This engine is an inline, 4-cylinder water-cooled unit which was introduced in 1974 with an 89.7-CID and enlarged in 1976 to 97-CID.

Rabbit models are offered as sedans and coupes and are placed in the 2250-pound inertia weight class. The Scirocco coupe also falls in this inertia weight class, while Dasher wagons and sedans are rated at 2500-pounds. Both the Rabbit and Dasher offer four-speed manual and three-speed automatic transmissions. Model years of interest are 1974-1976.

For the 1976 model year, the Dasher drivetrain is identical to the 1976 Audi Fox. In fact, results from emission certification tests of Audi Fox vehicles in 1976 are used to certify Dasher vehicles for compliance to both Federal and California emission statutes. For this reason, engine specifications for the 1976 Dasher are covered in the Audi Fox section of this report and specifications concerning the 1976 version of the VW 97-CID engine are applicable only to Rabbit and Scirocco vehicles. However, engine calibration and emission data for the 1976 Dasher are included in this section for comparison with 1974 and 1975 model year Dasher vehicles.

5.10.2 Engine Design Features

Tables 5-28 and 5-29 list key design features of the subject engines (Refs. 5-80 through 5-81). For the Beetle engine described in Table 5-28 the incorporation of Bosch L-Jetronic fuel injection in 1975 is a significant recent design change. In the case of the Rabbit-Scirocco engine, the 1976 increase in displacement and the introduction of a single venturi carburetor as an alternate to the two-venturi design are two significant design changes since introduction of the engine in 1974.

5.10.3 VW 96.7-CID Engine

5.10.3.1 Engine Modifications

The combustion chamber design of the subject engine has evolved from similar units of smaller capacity as indicated in Table 5-28. Because lean air/fuel mixtures are used in the 1976 California engines, the two passenger compartment heaters located in the exhaust system have been moved to a position further downstream from the combustion chamber than in

TABLE 5-28. ENGINE SPECIFICATIONS: VW 96.66-CID ENGINE

Engine Parameter	Model Year									
	1976		1975		1974		1970		1968	
	49 States	California	49 States	California	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4		4		4	
Bore, in.	3.366		3.366		3.366		3.366		-	
Stroke, in.	2.717		2.717		2.717		2.717		-	
Displacement, cu in.	96.66		96.66		96.66		96.66		91.1	
Surface/Volume, 1/in.	5.0		5.0		5.0		-		-	
Compression Ratio	7.3		7.3		7.3		7.5		7.5	
Cylinder Head Type	OHV		OHV		OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	48 at 4200		48 at 4200		48 at 4000		57 at 4400		53 at 4200	
Torque, ft-lb, at Engine Speed, rpm	75 at 2200		75 at 2200		72 at 2800		82 at 3000		78 at 2600	
Exhaust System Type	Single		Single		Single		Single		Single	
Combustion Chamber Configuration	Wedge		Wedge		Wedge		Wedge		Wedge	
Intake Valve Diameter, in.	1.304		1.304		1.400		-		-	
Intake Valve Lift, in.	0.352		0.352		0.306		-		-	
Exhaust Valve Diameter, in.	1.185		1.185		1.300		-		-	
Exhaust Valve Lift, in.	0.333		0.333		0.290		-		-	
Intake Valve Opens, deg BTC	10		10		7		-		-	
Intake Valve Closes, deg ABC	38		38		37		-		-	
Intake Valve Duration, deg	228		228		224		-		-	
Exhaust Valve Opens, deg BBC	43.5		43.5		44		-		-	
Exhaust Valve Closes, deg ATC	4.5		4.5		4		-		-	
Exhaust Valve Duration, deg	228		228		228		-		-	
Valve Overlap, deg	14.5		14.5		11		-		-	
Distributor Type	Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.		Breaker point; centrifugal & vacuum adv.	
Basic Ignition Advance at Idle, deg[a]	0 (A)[b] 5 ATC (M)[b]		0 (A)[b] 5 ATC (M)[b]		7.5 BTC[c]	7.5 BTC (A)[c] 5.0 ATC (M)[b]	0		-	
Idle Speed, rpm[a]	925 (A)[b] 875 (M)[b]		925 (A)[b] 875 (M)[b]		900 (A)[c] 850 (M)[c]	900 (A)[c] 850 (M)[b]	850		-	
Fast Idle Speed, rpm	-		-		-		-		-	
Intake Air Temperature Control	Thermostatic		Thermostatic		-		-		-	
Fuel System Type	Timed FI		Timed FI		1-V Carburetor		1-V Carburetor		1-V Carburetor	
Fuel Metering Method	Injection time regulated by airflow rate		Injection time regulated by airflow rate		Fixed orifice		-		-	
Enrichment Method	Increased injection time		Increased injection time		Fixed orifice		-		-	
Choke Type	Cold start injection		Cold start injection		Automatic		Automatic		-	
Carburetor Venturi Diameter, in.	-		-		1.023		-		-	
Fuel System Maximum Air Flow, cfm, at Vacuum, in. Hg	98		98		88 at 3		-		-	
Emission Control Systems	EGR EVAP FI PCV	CAT EGR EVAP FI PCV	EGR EVAP FI PCV	CAT EGR EVAP FI PCV	EGR EM EVAP PCV		EM EVAP PCV		AIR[d] EM PCV	
Emission Control Devices	Deceleration control valve[d]		Deceleration control valve[d]		Throttle closing damper		-		Vacuum limited deceleration control[d]	

[a] A = automatic transmission; M = manual transmission

[b] Dual diaphragm distributor with vacuum retard only at idle

[c] Single diaphragm distributor

[d] Manual transmission only

TABLE 5-29. ENGINE SPECIFICATIONS: VW 97-CID ENGINE

Engine Parameter	Model Year					
	1976[a]		1975		1974	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4	
Bore, in.	3.13		3.012		3.012	
Stroke, in.	3.15		3.15		3.15	
Displacement, cu in.	97		89.75		89.75	
Surface/Volume, 1/in.	5.48		5.64		5.64	
Compression Ratio	8.0		8.0		8.0	
Cylinder Head Type	OHC		OHC		OHC	
Advertised HP at Engine Speed, rpm	70 at 5600 (1V) 71 at 5600 (2V)		71 at 5800		75 at 6000	
Torque, ft-lb, at Engine Speed, rpm	86 at 3200 (1V) 86 at 3000 (2V)		80 at 4000		79 at 4000	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Disc in cylinder head		Disc in cylinder head		Disc in cylinder head	
Intake Valve Diameter, in.	1.34		1.34		1.34	
Intake Valve Lift, in.	0.406		0.406		0.406	
Exhaust Valve Diameter, in.	1.22		1.22		1.22	
Exhaust Valve Lift, in.	0.406		0.406		0.406	
Intake Valve Opens, deg BTC	4		7		4	
Intake Valve Closes, deg ABC	46		43		47	
Intake Valve Duration, deg	230		230		231	
Exhaust Valve Opens, deg BBC	44		47		43	
Exhaust Valve Closes, deg ATC	6		3		7	
Exhaust Valve Duration, deg	230		230		230	
Valve Overlap, deg	10		10		11	
Distributor Type	Breaker point; centrifugal and vacuum advance and vacuum retard (2V only)		Breaker point; centrifugal and vacuum advance and vacuum retard		Breaker point; centrifugal and vacuum advance and vacuum retard	
Basic Ignition Advance at Idle, deg	7.5 BTC (1V) 3.0 ATC (2V)		6 ATC	3 ATC	3 ATC	
Idle Speed, rpm	925		925		925	
Fast Idle Speed, rpm	-		-		-	
Intake Air Temperature Control	Thermostatic		Thermostatic		Thermostatic	
Fuel System Type	1V or 2V carburetor		2V carburetor		2V carburetor	
Fuel Metering Method	Fixed orifice		Fixed orifice		Fixed orifice	
Enrichment Method	Fixed orifice		Fixed orifice		Fixed orifice	
Choke Type	Automatic, bimetal		Automatic, bimetal		Automatic, bimetal	
Carburetor Venturi Diameter, in.	1.063 (1V) 0.945/1.063 (2V)		0.945/1.063		0.945/1.063	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	133 at 2.97 (1V) 120 at 2.13 (2V)		109.5 at 1.456		125 at 1.2	
Emission Control Systems[b]	AIR CAT EGR EVAP PCV		AIR EVAP PCV	AIR CAT EGR EVAP PCV	EGR EM EVAP PCV	
Emission Control Devices	A/C vacuum retard defeat[c] Coolant temperature control of:[c] second venturi enable vacuum ignition advance acceleration pump charge idle enrichment EGR enable Deceleration control valve[c] Secondary air bypass Throttle damper				Throttle damper	

[a] For 1976 this chart covers Rabbit/Scirocco vehicles only. See Audi engine specifications for the Dasher engine description (Table 5-1)

[b] 1975 California vehicle also offered as a 49-states vehicle

[c] 2V carburetor only

previous designs. This maintains higher temperatures in the exhaust gas and promotes oxidation of unburned HC.

As shown in Table 5-28, a wedge-shaped combustion chamber, a 7.3:1 compression ratio, and a 5.0:1 surface-to-volume ratio are current design parameters of the 96.7-CID engine. The current compression ratio is a reduction from 7.5:1 in 1970 and is one of the modifications incorporated to meet the more stringent NO_x emission standards for California. The 5.0:1 surface-to-volume ratio is one of the lowest of the engines surveyed in this report.

Valve timing changes from 1974 to 1975 show a slight increase in the amount of exhaust valve closing delay and a more marked increase in intake valve opening advance. This sort of change is usually associated with attempts to reduce HC as opposed to NO_x, however, some reduction of NO_x is also attained through the added charge dilution resulting from increased intake-exhaust valve overlap (Ref. 5-88).

5.10.3.2 Intake System

The intake air system is equipped with an air temperature control system of conventional design for the 1975 and 1976 model years. Control of the system is implemented by a thermostat located in the intake duct of the air cleaner. This unit senses the temperature of an air mixture composed of ambient underhood and engine heated air. Air temperature is also controlled by the thermostat, which moves a valve plate in the air duct to change the ratio of heated to unheated air admitted to the air cleaner.

5.10.3.3 Fuel System

In the 1975 and 1976 model years, VW uses the Bosch L-Jetronic fuel injection system on the 96.7-CID engine. Previous model year versions of this engine use a single one-venturi downdraft carburetor of conventional design as indicated in Table 5-28. As the carburetor is conventional, its description is limited to the brief summary in Section 5.10.3.3.2 and air/fuel ratio information introduced later. A description of the fuel injection system follows.

5.10.3.3.1 Fuel Injection System

The Bosch L-Jetronic fuel injection system is a time-modulated fuel delivery system with the quantity of fuel injected determined by the quantity of air delivered to the engine and by engine speed. The basic system is implemented by an electric fuel pump, an intake manifold, an intake air quantity measuring device, an electronic control unit, and electromagnetic injection valves located in the intake manifold near each engine cylinder intake valve. Additional components described later perform ancillary functions such as cold start enrichment.

Since all calculations determining injection pulse time are performed electronically, each variable engine parameter included in the calculation must be sensed and transduced to an electrical signal. In the case of the inlet air quantity measurement, this is accomplished by an air flow sensor, consisting of a spring-loaded flap valve and potentiometer. The flap valve is located in the inlet air passage upstream from the throttle valve and is positioned to allow an increased rate of inlet air flow to further open the flap valve against its spring restraint. The angular position of the flap valve about its shaft thus is a measure of the amount of inlet air flowing and is the variable transduced by the potentiometer for delivery to the electronic control unit.

Aside from an air quantity measurement, two other continuous variables are sensed, transduced, and provided to the electronic control unit for inclusion in the injection pulse-time calculation. These include an engine speed signal taken from the distributor in the form of a train of electrical pulses and an engine cylinder head temperature signal.

A discrete signal informs the electronic control unit of starter switch engagement. This signal is used to enable a cold start valve which injects additional fuel into the common intake manifold for a fixed time period during engine cranking. Control of the time period is implemented by a time-related temperature switch with an electrically heated bimetal sensing element. This switch is mounted in a location that makes it sensitive to engine temperature so that the cold start valve injection time is inversely proportional to engine temperature during startup. No enrichment is provided above an engine temperature of 55°F, while a 22-millisecond injection time is programmed at an ambient temperature of -4°F.

After engine startup, enrichment is implemented via the four normal injection valves and based on sensed cylinder head temperature. In addition, increased air flow is provided for a faster cold idle speed. This is mechanized with an electrically assisted engine-heated bimetal auxiliary air valve which bypasses the throttle valve and has a cross section dependent on engine temperature. At idle, the auxiliary air valve provides all engine intake air as the throttle is completely closed.

Vehicles with manual transmission are equipped with a deceleration control valve to limit intake manifold vacuum and the formation of unburned HC during vehicle deceleration. This valve provides additional air to the engine from upstream of the throttle valve during deceleration. System plumbing is arranged so that the additional intake air flow provided by the deceleration control valve is sensed by the fuel injection air flow sensor. An additional discrete signal is provided to the electronic control unit by a throttle valve switch. This switch provides inputs for full-load enrichment and EGR control as described later.

In order to assure that the amount of fuel delivered by each of the injectors is dependent only on their open time, the line fuel pressure is regulated to a constant 36 psi above intake manifold pressure. This function is implemented by a precision overflow pressure control device and a fuel pump which delivers 20-40 liters/hr more fuel than the maximum engine requirement. Excess fuel is returned to the tank.

In the L-Jetronic system, all injection valves are electrically paralleled, and thus all valves inject simultaneously. This means that individual cylinders receive their fuel charge at different phases in their combustion cycle. Also, in this system, half of the fuel quantity required for one combustion cycle is injected for each crankshaft revolution. This causes the fuel needed for an individual cylinder firing to be delivered in two distinct pulses.

5.10.3.3.2 Carburetor

5.10.3.3.2.1 Design Features

In 1974 and prior model year vehicles, a single venturi carburetor of conventional design using fixed orifice metering and enrichment systems is used with the subject engine. An electrically assisted choke is used on 1974 models, and a deceleration controller is fitted on 1968 manual transmission equipped vehicles. The controller delays closing of the throttle during deceleration by 3-4 seconds to assist in the control of HC and CO.

5.10.3.3.2.2 Air/Fuel Ratio

Table 5-30 presents carburetor air/fuel ratios for the 1970 and 1974 model years. As indicated, somewhat leaner ratios are used in

TABLE 5-30. CERTIFICATION CALIBRATION DATA: VW 96.66-CID ENGINE

Engine/Vehicle Parameter	Model Year and Certification Standard																	
	1976 49 States			1976 California[a]		1975 49 States				1975 California				1974 49 States and California			1970	
Vehicle Model	B[b]	B[b]	B[c]	B[b]	B[c]	B[b]	B[b]	B[b]	B[c]	B[b]	B[b]	B[b]	B[c]	B[b]	K[d]	B[c]	B[b]	B[b]
Transmission Type	M4	M4	M4	M4	M4	M4	M4	A	A	M4	M4	A	A	M4	M4	A	M4	A
Vehicle Inertia Weight, lb	2250	2250	2500	2250	2500	2250	2250	2250	2500	2250	2250	2250	2500	2250	2250	2500	2250	2250
Rear Axle Ratio	3.88	3.88	3.88	3.88	3.88	3.88	3.88	4.38	4.38	3.88	3.88	4.38	4.38	3.88	3.88	4.12	4.12	4.38
Catalyst	No	No	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No
No. of Carburetory Venturi's	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	FI	1	1	1	1	1
Carburetor Calibration, A/F																		
Idle: 20-kg/hr air flow	-	-	-	-	-	-	-	-	-	-	-	-	-	15.1	15.1	15.2	13.5[e]	13.5[e]
Off Idle: 45-kg/hr air flow	-	-	-	-	-	-	-	-	-	-	-	-	-	16.4	16.4	16.6	16.3	16.3
Part Throttle: 65-kg/hr air flow	-	-	-	-	-	-	-	-	-	-	-	-	-	17.2	17.2	17.4	14.6[f]	13.8[f]
WOT:at Max: 180-kg/hr air flow	-	-	-	-	-	-	-	-	-	-	-	-	-	12.4	12.4	12.2	12.5	12.5
Basic Timing, crankshaft deg	5 ATC	5 ATC	5 ATC	5 ATC	5 ATC	5 ATC	5 ATC	0	0	5 ATC	5 ATC	0	0	5 ATC	5 ATC	7.5 BTC	0	0
Centrifugal Advance, crankshaft deg																		
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
1500 rpm	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	15.0	11.0
2000 rpm	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	20.0	14.0
3000 rpm	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	27.0	20.0
4000 rpm	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	27.0	27.0
5000 rpm	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	27.0	27.0
Vacuum Advance, crankshaft deg																		
100 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
125 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	6.0	2.5
150 mm Hg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	2.0	2.0	3.0	3.0	2.0	2.0	5.0	11.0	4.5
175 mm Hg	5.0	5.0	5.0	5.0	5.0	5.0	5.0	7.0	7.0	5.0	5.0	7.0	7.0	5.0	5.0	8.5	15.0	6.5
200 mm Hg	6.5	6.5	6.5	6.5	6.5	6.5	6.5	10.0	10.0	6.5	6.5	10.0	10.0	6.5	6.5	10.0	18.0	8.5
250 mm Hg	6.5	6.5	6.5	6.5	6.5	6.5	6.5	10.0	10.0	6.5	6.5	10.0	10.0	6.5	6.5	10.0	18.0	10.0
300 mm Hg	6.5	6.5	6.5	6.5	6.5	6.5	6.5	10.0	10.0	6.5	6.5	10.0	10.0	6.5	6.5	10.0	18.0	10.0
EGR Valve Calibration																		
Signal Pressure To Open, mm Hg	30	30	30	30	30	30	30	30	30	30	30	30	30	82	82	82	-	-
Flow at 70-mm Hg, cfm	15	15	15	15	15	15	15	15	15	15	15	15	15	5[g]	5[g]	5[g]	-	-
Fuel Economy, mpg																		
City	23	22	23	26	24	22	23	21	21	25	21	21	21	20.9	21.7	22.6	-	-
Highway	35	33	32	38	35	33	35	30	26	34	35	31	30	-	-	-	-	-
Exhaust Emission, g/m																		
HC	1.4	1.1	1.2	0.8	0.3	1.1	1.4	1.1	1.2	0.4	0.5	0.4	0.5	2.5	2.1	3.4	-	-
CO	8.0	6.0	8.0	7.7	3.6	6.0	8.0	8.0	10.0	6.5	8.2	7.0	6.7	25.0	25.0	32.0	-	-
NO_x	1.5	1.3	2.1	1.4	1.4	1.3	1.5	1.5	1.6	0.7	0.8	1.3	1.2	2.0	1.8	1.8	-	-

[a] Also offered as a 49-state vehicle

[b] Beetle sedan

[c] Beetle convertible

[d] Karman Ghia

[e] At 16-kg/hr

[f] At 110-kg/hr

[g] At 2000-mm Hg

1974 compared with 1970. This modification, in conjunction with ignition timing changes, is used to meet the increasingly stringent HC and CO emission requirements implemented between 1970 and 1974.

5.10.3.4 Ignition System

5.10.3.4.1 Design Features

VW uses a conventional breaker-point ignition system on its 96.7-CID engine for all model years of interest. As indicated in Table 5-28, vacuum ignition retard implemented with a dual diaphragm distributer is used in recent model years. Vacuum retard, effective only during idle and closed throttle deceleration, is used to promote post-combustion oxidation of HC in the exhaust system. Maximum ignition retard is 12 engine crankshaft deg on manual transmission vehicles and 7 crankshaft deg on semiautomatic transmission cars.

5.10.3.4.2 Spark Advance Schedules

As shown in Table 5-30, a substantial overall reduction of ignition advance exists between 1970 and 1974 model year vehicles using the subject engine and manual transmissions. From 1974 through 1976, the ignition advance shows no change for both manual and semiautomatic vehicles although the HC and CO emission standards are lowered substantially. This is made possible by the 1975 addition of fuel injection on 49-states vehicles and by the addition of fuel injection and oxidizing catalysts on California vehicles. The tolerance bands for both centrifugal and vacuum advance have remained nearly constant over the past several years, varying between about ±3 deg at low speeds and low-vacuum levels and about ±1.5 deg in the high-speed and high-vacuum regimes.

5.10.3.5 Exhaust Gas Recirculation

5.10.3.5.1 Design Features

For the 1975 and 1976 vehicles shown in Table 5-30, the 49-states and California EGR systems are the same, except that 49-states units use an EGR filter while California vehicles have an EGR cooling line in place of the filter. In these systems, the vacuum signal to the single stage EGR valve is controlled electrically by a solenoid which in turn is activated by a throttle switch. The throttle switch is set to provide EGR for all load conditions except at idle, at WOT, and during deceleration.

An EGR maintenance indicating lamp, mounted on the instrument panel, is actuated each 15,000 miles to remind the vehicle operator that maintenance is due. During maintenance, the counter is reset to zero and reactivation occurs following another 15,000 miles of vehicle operation.

The 1974 49-states and California vehicles listed in Table 5-30 use a two-stage EGR device. The first stage is operated by a vacuum signal obtained from a tap located 1 millimeter above the throttle at idle position. At higher loads (for throttle opening angles larger than 12 deg, a microswitch actuates a solenoid which connects the high vacuum source to the EGR valve. This causes the second stage of the valve to come into play and the EGR flow rate is increased.

5.10.3.5.2 EGR Valve Calibration

Table 5-30 presents EGR Valve flow rates for the 1974 through 1976 model years. As shown EGR is higher in 1975 and 1976 than when first introduced in 1974. Since ignition timing has remained unchanged between 1974 and 1975 in the vehicles with manual transmission, a decline in NO_x would be expected for this time period. This is the case as may be seen by referring to Table 5-30. In the case of vehicles equipped with semiautomatic transmission, the observed reduction in NO_x in 1975 results from increased EGR flow rates and retarded ignition timing.

5.10.3.6 Secondary Air Injection

VW does not currently use secondary air injection on its 96.7-CID engine, however, secondary air is used in 1968 model year vehicles. The system is of conventional design consisting of an engine-driven air pump, a distribution manifold, a check valve, and a diverter valve. The system is functionally similar to the configurations used by other manufacturers.

5.10.3.7 Catalytic Converter

For the 1975 and 1976 model years, California vehicles using the 96.7-CID engine have an oxidizing catalytic converter as indicated in Table 5-28. These models are offered also as 49-states vehicles. The composition of the catalyst is 85-95 percent platinum with the remainder composed of a rhodium promoter. Catalytic material is applied in liquid form to an extruded monolithic substrate and baked. The catalyst container is cylindrical with a 4-inch diameter and is 6 inches long. Approximately 335 cc of effective catalyst volume is available.

A catalyst replacement light is incorporated in the instrument cluster and is activated at 30,000 vehicle miles by a mileage counter. Replacement of the catalyst is mandatory in order to maintain California exhaust emission standards.

5.10.3.8 Crankcase and Evaporative Emission Control

A conventional crankcase emission control system of the type described in Section 3 is used on the subject engine. In 1976, the PCV valve has been replaced by a simple orifice.

An evaporative control system much like the system described in Section 3 and using a limited-fill fuel tank to obtain expansion volume with an activated carbon canister to store fuel vapor is used by VW with the subject engine. Venting of the canister is provided at engine startup by air pressure from the engine cooling fan and vacuum from the intake manifold via the air cleaner. Stored fuel vapor from the canister is thus drawn into the clean side of the air cleaner and burned in the normal combustion process.

5.10.3.9 Fuel Economy and Emissions

Figure 5-36 presents a plot of city fuel economy versus model year for the subject engine. The data presented are based on averages developed from fuel economy figures for VW Beetle sedans and convertibles equipped with both semiautomatic and manual transmission, (Refs. 5-8, 5-10, 5-13, and 5-20). The plotted results have been normalized to an axle ratio of 3.88 and an inertia weight of 2250 pounds according to the method described in Section 3. In addition, a 5 percent adjustment in 1973 and 1974 fuel economy has been made to account for differences in the CVS-C and CVS-CH test procedures.

As seen in Figure 5-36, the fuel economy for vehicles equipped with manual transmission exhibits a decline of approximately 7 percent from 1973 to 1974. The decline is attributed directly to the decrease in the California NO_x standard from 1973 to 1974 as all vehicles forming the 1974 data base for Figure 5-36 are certified to California emission requirements. These vehicles and their calibration data are listed in Table 5-30.

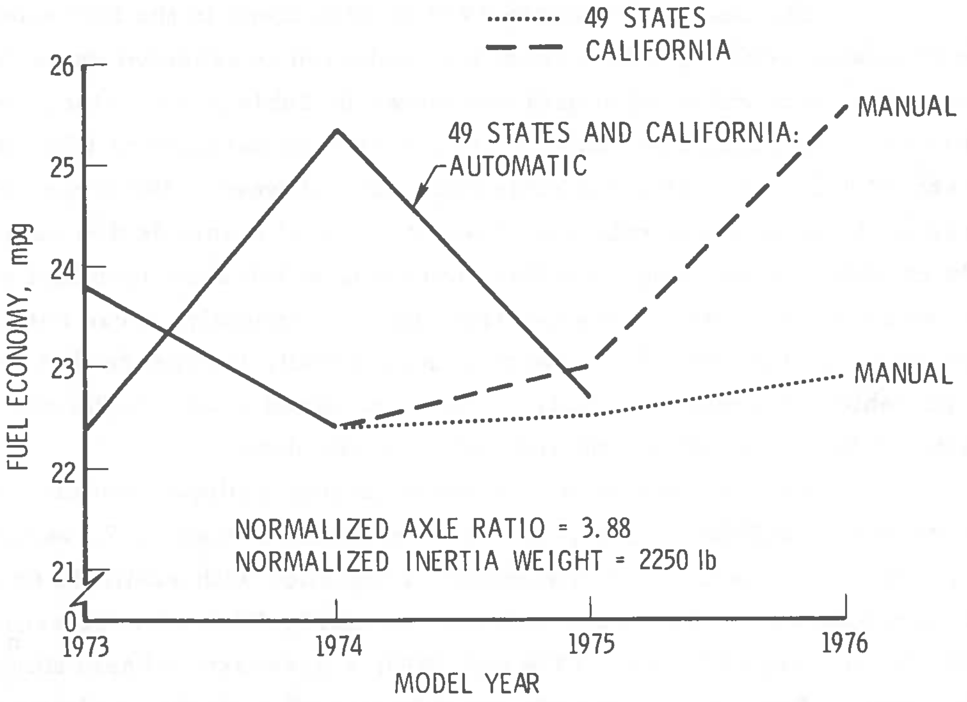


FIGURE 5-36. NORMALIZED AVERAGE CITY FUEL ECONOMY: VW 96.66-CID ENGINE; BEETLE VEHICLE

Increases in manual transmission vehicle fuel economy for both 49-states and California cars between 1974 and 1975 are small enough to be considered essentially unchanged. On the basis of the calibration and emission data presented in Table 5-30, this is difficult to rationalize as valve overlap and EGR are higher in 1975, while other calibration data remain unchanged. These changes lead to an expectation of lower 1975 fuel economy, which is not the case as shown in Figure 5-36. However, as shown in Table 5-30, the 1975 vehicles require heavier engine loads before the EGR valve initially opens, and this may be a factor offsetting the higher maximum EGR levels. Also, a design change in the EGR system which has occurred between 1974 and 1975 and is explained in Section 5.10.3.5 may have resulted in a lower EGR flow rate increase than indicated by valve calibration data alone. This makes year-to-year comparison of EGR rates based on steady flow valve calibrations difficult. Therefore, based on these considerations, the subject fuel economy trend is considered to be well within normal test-to-test tolerance bands.

The nearly unchanged 1975 to 1976 trend in the fuel economy of the 49-states vehicles with manual transmission is expected as no year-to-year changes in calibration data are shown in Table 5-30. Also, two of the three 1976 certification vehicles represent 1975 carryovers with identical 1975 and 1976 fuel economy and emission data. However, the large 1976 divergence between California and 49-states manual transmission vehicles is totally at odds with the subject calibration data, which show identical settings for these cars. In order to resolve this apparent anomaly, these data have been discussed with EPA and VW personnel. As a result, it appears that test-to-test and vehicle-to-vehicle variations have combined to create the subject inconsistency between calibration and fuel economy data.

For the semiautomatic transmission equipped vehicle, the fuel economy curve exhibits a 1974 peak with the lower 1973 and 1975 values very nearly equal. In this case, a reasonable correlation with available spark advance data exists. While centrifugal and vacuum ignition advance remain essentially unchanged between 1974 and 1975, a decrease in basic timing of 7.5 deg is noted in Table 5-30, and this correlates well with the declining trend of the fuel economy curve between 1974 and 1975. Also, as mentioned previously, EGR flow rates and engine valve overlap are both higher in 1975 compared with 1974 as indicated by the observed NO_x emissions and EGR valve calibrations. Thus, the 1974 to 1975 fuel economy trend for vehicles equipped with semiautomatic transmission correlates well with available calibration data.

Since the engine calibration data for the 1973 vehicles with semiautomatic transmission are not presented in Table 5-30, the 1973 to 1974 fuel economy increase is included without rationalization. However, since the California NO_x standard has decreased between 1973 and 1974, a reduction in 1974 fuel economy would be expected because of the required higher EGR flow and/or retarded timing. Since the opposite trend has occurred test-to-test and vehicle-to-vehicle variations must be assumed to be the cause.

5.10.4 VW 89.7- and 97-CID Engines

5.10.4.1 Engine Modifications

For 1976, the subject engine has been increased in displacement to 97-CID from a previous 89.7-CID. As a result, a slight decrease in surface-to-volume ratio has occurred as may be noted in Table 5-29.

Intake-exhaust valve overlap has changed little since its introduction in 1974 although the emphasis on intake valve opening advance versus exhaust valve closing delay has shifted more noticeably. The most recent change, while maintaining overlap constant between the 1975 and 1976 model years, increases exhaust valve closing delay and decreases intake valve opening advance. This is usually indicative of an emphasis on control of NO_x emissions (Ref. 5-88).

Earlier 1974 to 1975 changes in valve timing shown in Table 5-29 have maintained overlap nearly constant but have cut exhaust valve closing delay by 4 deg while advancing intake valve opening by 3 deg. This is indicative of an emphasis on HC control (Ref. 5-88) to meet the more stringent 1975 HC and CO standards.

5.10.4.2 Intake System

Carbureted versions of the subject engine are equipped with a thermostatic air inlet control system. The 1976 version of the system is implemented with a wax thermostat which senses the temperature of an air mixture composed of exhaust manifold heated air and ambient underhood air. The air mixture is maintained at a nominal 86°F by the thermostat, which moves a valve plate to control the heated to ambient air mixture ratio.

5.10.4.3 Fuel System

In 1976, VW introduced the Bosch CIS on the Dasher while retaining a carburetor-based fuel system on the Rabbit and Scirocco models. As the CIS is identical to that used on the 1976 Audi Fox (Section 5.1.3), its description is not repeated here. However, a description of the Rabbit and Scirocco carburetor is presented in the following section.

5.10.4.3.1 Design Features

5.10.4.3.1.1 Two-Venturi Carburetor

Since its introduction, VW has used a single two-venturi carburetor on the subject engine. In 1974 a Solex unit was fitted, while more recent model years use a Zenith design.

The choke system on the 1974 engine uses a coolant-heated temperature sensor-actuator implemented with a bimetallic spring. For the 1975 and 1976 model years, an electrical heater is also used in conjunction with coolant supplied heat to reduce choke action time. In addition, a vacuum-actuated two-stage choke pulldown diaphragm is used on 1976 models to provide different levels of enrichment during and immediately after engine startup. The second stage of this unit is sensitive to engine compartment temperature, while the first stage is a standard pulldown initiated when the engine is started. In 1975, pulldown action is single stage and is delayed by a time delay valve in the vacuum line with delay proportional to intake manifold vacuum. Time delays range from 2 seconds at 50-mm Hg vacuum to 11 seconds at 250-mm Hg. On 1974 and 1975 models, a solenoid valve is used to block idle fuel supply to prevent dieseling after the ignition is shut off, while in 1976 a fixed-screw arrangement is used.

Fuel/air mixture preparation and enrichment are implemented as fixed orifice designs using calibrated fuel metering and air correction jets. Enrichment provided by the accelerator pump is controlled by a thermal vacuum valve and varies depending on coolant temperature. For cold engine operation, approximately 1.5 cc of fuel are injected per pump stroke, while above 136°F coolant temperature the amount is reduced to about 0.9 cc.

To prevent cold engine stall during sudden stops, the 1976 model year idle system is enriched for engine coolant temperatures below 63°F. Enrichment is implemented with a thermally controlled cold idle enrichment valve. Also, to improve cold engine acceleration characteristics, the second stage (venturi) of the carburetor is closed by another thermal vacuum valve for engine coolant temperature below 115°F.

A deceleration control valve actuated by intake manifold vacuum is also employed. This valve allows additional air, supplied by the secondary air pump, to enter the intake manifold during engine decelerations. The additional air is used to lean the rich air/fuel mixture associated with deceleration and thereby decrease HC and CO in the exhaust gas. A throttle closing damper is used in conjunction with the deceleration control valve to provide rate-limited throttle closure.

5.10.4.3.1.2 Single-Venturi Carburetor

The single venturi carburetor used with the subject engine is a downdraft Solex type employing a fixed orifice fuel metering system. A choke system similar to the previously described two-venturi carburetor is used; however, the bimetal actuator is heated only by electrical means. A single-stage vacuum-actuated pulldown diaphragm provides initial choke plate clearance immediately following engine startup, and an idle stop solenoid is fitted. Rate-limited throttle closures are provided by a throttle closing damper.

5.10.4.3.2 Air/Fuel Ratio Schedules

Tables 5-31 and 5-32 present carburetor air/fuel ratios for this engine. Dasher vehicles certified for California show a change to richer settings between 1974 and 1975. This is a result of the 1975 addition of a secondary air and catalyst system which requires richer engine intake mixtures to perform the task of post-combustion oxidation. The two-venturi carburetor settings for Rabbit vehicles show richer 1976 as opposed to 1975 settings. These adjustments are a reflection of a change from a secondary air/retarded spark emission control approach to a catalyst/secondary air/EGR based system.

5.10.4.4 Ignition System

5.10.4.4.1 Design Features

VW uses a conventional breaker-point ignition system on the subject engine. Generally, centrifugal and vacuum ignition advance, as well as vacuum ignition retard effective only at idle and during deceleration, are used. However, on single-venturi carburetor engines, vacuum retard is not used. A dual diaphragm distributor employed in conjunction with vacuum ports placed above and below the closed position of the carburetor throttle plate implements the respective vacuum advance and retard functions. Maximum retard is typically 9 engine crankshaft deg.

For 1975 and 1976, vacuum advance on two-venturi carburetor engines is controlled by a thermal vacuum switch (TVS) sensitive to coolant temperature. The switch enables vacuum advance for coolant temperatures above 136 $\pm 5^{\circ}$F. Vacuum retard is continuously enabled at engine idle speed, except on vehicles with A/C, which have vacuum retard defeated during A/C operation. This prevents the engine from stalling at idle because of compressor loads and helps to diminish HC and CO emissions.

TABLE 5-31. CERTIFICATION CALIBRATION DATA: VW 97- AND 89.75-CID ENGINE; DASHER

Engine/Vehicle Parameter	Model Year and Certification Standard													
	1976 49 States		1976 California		1975 49 States		1975 California[a]				1974 California[a]			
Vehicle Model	DW[b]	DS[c]	DW[b]	DS[c]	DS[c]	DW[b]	DW[b]	DS[c]	DW[b]	DS[c]	DS[c]	DW[b]	DS[c]	DS[c]
Transmission Type	M4	A3	M4	A3	M4	M4	M4	M4	A3	A3	M4	A3	A3	A3
Vehicle Inertia Weight, lb	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Rear Axle Ratio	4.11	3.91	4.11	3.91	4.11	4.11	4.11	4.11	3.91	3.91	4.11	4.09	4.09	4.09
Catalyst	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No
No. of Carburetor Venturi's	FI	FI	FI	FI	2	2	2	2	2	2	2	2	2	2
Carburetor Calibration, A/F														
Idle: 20-kg/hr air flow	15.0	15.0	15.0	15.0	13.3	13.3	14.0	14.0	14.0	14.0	15.0	15.0	15.0	15.0
Off Idle: 45-kg/hr air flow	15.0	15.0	15.0	15.0	15.6	15.6	14.6	14.6	14.6	14.6	15.4	15.4	15.4	15.4
Part Throttle: 65-kg/hr air flow	15.4	15.4	15.4	15.4	16.3	16.3	15.1	15.1	15.1	15.1	16.2	16.2	16.2	16.2
WOT at Max: 265-kg/hr air flow	14.3	14.3	14.3	14.3	15.1	15.1	14.2	14.2	14.2	14.2	14.8	14.8	14.8	14.8
Basic Timing, crankshaft deg	3 ATC	3 ATC	3 ATC	3 ATC	6 ATC	6 ATC	3 ATC	3 ATC	3 ATC	3 ATC	3 ATC	3 ATC	3 ATC	3 ATC
Centrifugal Advance, crankshaft deg														
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3000 rpm	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
4000 rpm	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
5000 rpm	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Vacuum Advance, crankshaft deg														
100 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150 mm Hg	0.0	0.0	0.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200 mm Hg	0.0	0.0	0.0	0.0	7.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
250 mm Hg	3.0	3.0	3.0	3.0	7.0	7.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
300 mm Hg	6.0	6.0	6.0	6.0	7.0	7.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
350 mm Hg	6.0	6.0	6.0	6.0	7.0	7.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
400 mm Hg	6.0	6.0	6.0	6.0	7.0	7.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
EGR Valve Calibration														
Signal Pressure To Open, in. Hg	5.0	5.0	5.0	5.0	-[d]	-[d]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]	5.5[e] 1.8[f]
Flow at 12-in. Hg, cfm	11.2	11.2	11.2	11.2	-[d]	-[d]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]	1.3[e] 6.0[f]
Fuel Economy, mpg														
City	24	25	24	-	24	22	23	23	24	22	22.7	23.7	22.7	21.2
Highway	37	33	36	-	39	34	38	38	32	33	-	-	-	-
Exhaust Emissions, g/m														
HC	1.0	1.3	0.2	-	0.7	1.3	0.4	0.3	0.3	0.2	-	-	-	-
CO	5.0	4.0	2.0	-	10.0	6.0	3.9	1.5	1.4	1.9	-	-	-	-
NO_x	2.2	1.9	1.2	-	1.9	2.2	1.2	1.1	1.4	1.1	-	-	-	-

[a] Also offered as 49-states vehicle

[b] Dasher wagon.

[c] Dasher sedan.

[d] No EGR.

[e] Stage 1

[f] Stage 2

TABLE 5-32. CERTIFICATION CALIBRATION DATA: VW 97- AND 89.75-CID ENGINES; RABBIT AND SCIROCCO

Engine/Vehicle Parameter	Model Year and Certification Standard										
	1976 49 States		1976 California[a]			1975 49 States		1975 California[a]			
Vehicle Model	RS[b]	RS[b]	RS[b]	RS[b]	RS[b]	R[c]	S[d]	R[c]	S[d]	R[c]	S[d]
Transmission Type	M4	A3	M4	M4	A3	M4	M4	M4	M4	A3	A3
Vehicle Inertia Weight, lb	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250
Rear Axle Ratio	3.90	3.76	3.70	3.90	3.76	3.90	3.90	3.90	3.90	3.76	3.76
Catalyst	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
No. of Carburetor Venturi's	2	2	1	2	2	2	2	2	2	2	2
Carburetor Calibration, A/F											
Idle: 15-kg/hr air flow	14.0	14.0	15.0	14.0	14.0	14.3	14.3	14.0	14.0	14.0	14.0
Off Idle: 45-kg/hr air flow	14.1	14.1	15.1	14.1	14.1	16.4	16.4	15.6	15.6	15.6	15.6
Part Throttle: 65-kg/hr air flow	14.9	14.9	16.9	14.9	14.9	16.6	16.6	15.9	15.9	15.9	15.9
WOT at Max.: 185-kg/hr air flow	-	-	14.9	-	-	-	-	-	-	-	-
Basic Timing, crankshaft deg	3 ATC	3 ATC	7.5 BTC	3 ATC	3 ATC	6 ATC	6 ATC	3 ATC	3 ATC	3 ATC	3 ATC
Centrifugal Advance, crankshaft deg											
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500 rpm	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2000 rpm	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
3000 rpm	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
4000 rpm	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
5000 rpm	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Vacuum Advance, crankshaft deg											
100 mm Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150 mm Hg	0.0	0.0	0.0	0.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0
200 mm Hg	0.0	0.0	0.0	0.0	0.0	5.0	5.0	0.0	0.0	0.0	0.0
250 mm Hg	3.0	3.0	3.0	3.0	3.0	5.0	5.0	3.0	3.0	3.0	3.0
300 mm Hg	9.0	9.0	9.0	9.0	9.0	5.0	5.0	9.0	9.0	9.0	9.0
350 mm Hg	13.0	13.0	13.0	13.0	13.0	5.0	5.0	13.0	13.0	13.0	13.0
400 mm Hg	13.0	13.0	13.0	13.0	13.0	5.0	5.0	13.0	13.0	13.0	13.0
EGR Valve Calibration											
Signal Pressure To Open, in. Hg	5.5	5.5	3-mm lift[e]	5.5[g] 1.8[h]	5.5[g] 1.8[h]	-[i] -[i]	-[i] -[i]	5.5[g] 1.8[h]	5.5[g] 1.8[h]	5.5[g] 1.8[h]	5.5[g] 1.8[h]
Flow at 12-in. Hg, cfm	1.3	1.3	9[f]	1.3[g] 6.0[h]	1.3[g] 6.0[h]	-[i] -[i]	-[i] -[i]	1.3[g] 6.0[h]	1.3[g] 6.0[h]	1.3[g] 6.0[h]	1.3[g] 6.0[h]
Fuel Economy, mpg											
City	25	24	29	26	25	24	23	24	25	24	25
Highway	39	35	43	38	36	39	36	41	40	35	35
Exhaust Emissions, g/m											
HC	0.2	0.3	-	0.3	0.2	1.4	0.8	0.2	0.2	0.2	0.2
CO	5.0	9.0	-	4.8	3.6	10.0	7.0	0.9	1.1	2.6	2.4
NO_x	1.0	1.1	-	0.8	1.5	1.9	1.6	1.4	1.1	1.3	1.0

[a] Also offered as 49-States vehicle

[b] Rabbit; Scirocco

[c] Mechanically actuated EGR

[d] Scirocco

[e] Rabbit

[f] At maximum flow

[g] Stage 1

[h] Stage 2

[i] No EGR

5.10.4.4.2 Spark Advance Schedules

Table 5-31 presents spark advance schedules for the Dasher vehicle. As indicated, the centrifugal advance has remained unchanged over the years; however, vacuum advance and basic timing show substantial changes. Ignition timing for California vehicles remains constant between 1974 and 1975. The added emission control burden in 1975 is taken up by the addition of a secondary air and catalyst system. For 1975 49-states vehicles which do not use catalysts or EGR, retarded vacuum spark advance assists in the control of HC, CO, and NO_x. In 1976, a basic change in the EGR system associated with a change to fuel injection led to additional decreases in vacuum advance for the low-load regime.

For Rabbit vehicles, ignition timing shown in Table 5-32 is unchanged between 1975 and 1976, except that lower vacuum advance and retarded basic timing is used in the 1975 49-states vehicles. These vehicles are equipped with secondary air but do not use a catalyst or EGR; therefore, more of the emission control burden falls on the ignition system.

For each certification standard within each model year, the same spark advance schedules are used for both manual and automatic transmission vehicles.

5.10.4.5 Exhaust Gas Recirculation

The EGR system used on 1976 49-states Rabbit and Scirocco vehicles with a two-venturi carburetor meters exhaust gas via a cooling line and a single-stage EGR valve actuated by carburetor port vacuum. The 1974 and 1975 California Dasher vehicles and the 1975 and 1976 California Rabbit and Scirocco vehicles with a two-venturi carburetor uses a system with a two-stage EGR valve. In this system, vacuum for the second stage is taken from the power brake booster, which is a high vacuum source, and is switched on and off by a solenoid sensitive to throttle position. Second-stage EGR is provided in the mid-load regime but is shut off by the solenoid at WOT. At WOT, first-stage EGR is also zero because of the low level of carburetor port vacuum associated with high air flow rates.

For 1976 Rabbit and Scirocco engines equipped with a single-venturi carburetor, a throttle linkage actuated EGR valve rather than a vacuum-actuated valve is used. The valve flow rate is programmed to rise in an approximately linear manner as a function of throttle position to a maximum level and then decrease rapidly to zero flow at WOT.

Thermal vacuum valves sensitive to engine coolant are used to defeat each EGR circuit on two-venturi carbureted engines when coolant temperature is below 115°F. The mechanical EGR valve used on single-venturi carburetor engines is not modulated by coolant temperature.

The EGR system used in the fuel-injected 1976 Dasher engines is a venturi vacuum-actuated system with a vacuum amplifier, which is identical to the configuration used in the Audi Fox (Section 5.1.3).

A mileage counter driven, dash-mounted EGR maintenance warning lamp is actuated every 15,000 miles to alert the vehicle operator that EGR maintenance is due. The lamp remains on until the counter is reset by service personnel.

5.10.4.6 Secondary Air Injection

As indicated in Tables 5-31 and 5-32, a conventional secondary air injection system is used on some VW 89.7- and 97-CID engines. As mentioned previously (see Section 5.10.4.3.1.1), the system supplies air to the deceleration control valve in addition to providing air to engine exhaust ports. Also, in order to protect the catalyst from overheating an ABPV is used to dump the air pump output to atmosphere at high engine speeds and loads.

5.10.4.7 Catalytic Converter

A catalytic converter is used with some 1975 and 1976 models as shown in Tables 5-31 and 5-32. The catalyst is essentially the same as described in Section 5.10.3.7 and includes the maintenance reminder lamp described in that section. An added feature is a "catalyst overheated" indicator. This is implemented by a thermocouple mounted in the exhaust pipe downstream of the catalytic converter, a flasher, and the previously noted catalyst maintenance lamp. Engine exhaust gases with temperatures approaching a level which may harm the catalyst cause the lamp to flash on and off in order to inform the vehicle operator of the potential problem.

5.10.4.8 Crankcase and Evaporative Emission Control

A conventional closed crankcase emission control system in which all crankcase gases flow to the intake system upstream of the carburetor is used with the subject engine. Dasher and Rabbit installations are essentially the same, except that a PCV valve is included on the 1975 Rabbit while the 1975 Dasher uses a simple orifice in place of the valve. For 1976, both the Dasher and Rabbit use an orifice.

The evaporative emission control system is functionally much the same as the one described for the Beetle, except that the engine cooling fan is not used to aid purging of the charcoal canister.

5.10.4.9 Fuel Economy and Emissions

Fuel economy and emissions for the VW 97- and 89.7-CID engines are treated separately for the Dasher and the Rabbit-Scirocco vehicles as they each use substantially different fuel systems. As with the previously discussed Beetle, vehicle normalized axle ratio and inertia weight are used in order to place year-to-year fuel economy data on an equivalent basis. The same general comments made regarding the normalizing process used with Beetle data also apply to data presented for the Rabbit-Scirocco and Dasher vehicles.

5.10.4.9.1 Rabbit and Scirocco Fuel Economy and Emissions

Figure 5-37 presents fuel economy data for Rabbit and Scirocco vehicles equipped with manual transmission. As seen both 49-states and California vehicles equipped with a two-venturi carburetor exhibit a 1975 to 1976 fuel economy improvement amounting to about 1.5 mpg. In the case of 49-states vehicles, the improvement may be attributed to an increase in vacuum advance and more advanced basic timing as shown in Table 5-32. The increase in vacuum advance is made possible by the introduction of an oxidizing catalyst and EGR. Table 5-32 shows that the improvement in economy is accompanied by improved HC, CO, and NO_x emission control.

The improved California vehicle fuel economy is more difficult to rationalize as system calibration data shown in Table 5-32 do not change between 1975 and 1976. The observed variations are attributed to normal test-to-test and vehicle-to-vehicle tolerances.

The single-venturi carburetor equipped version of the subject engine has been only recently introduced; therefore, no previous data are available for comparison. However, the two-venturi data show nearly a 3-mpg improvement. This is especially impressive as the single-venturi carburetor engine employs a simple all-mechanical EGR system which meters exhaust gas based only on throttle linkage position.

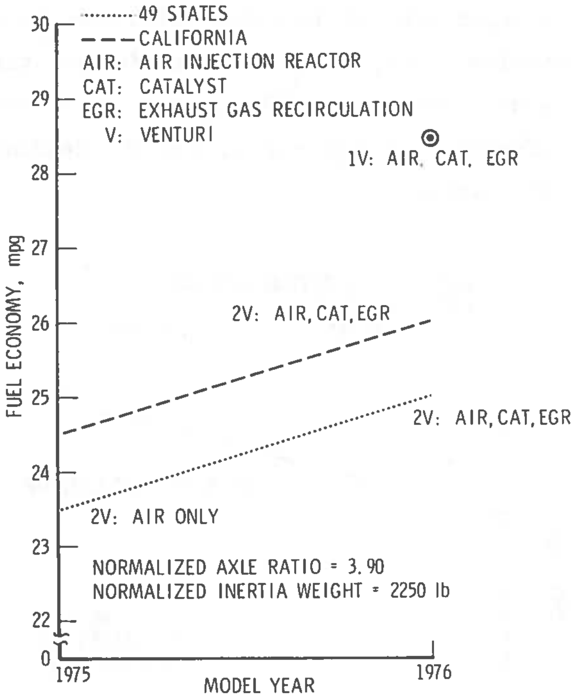


FIGURE 5-37. NORMALIZED AVERAGE CITY FUEL ECONOMY: VW 97- AND 89.7-CID ENGINES; RABBIT MANUAL TRANSMISSION VEHICLE

Figure 5-38 presents fuel economy data for Rabbit vehicles equipped with an automatic transmission. As expected, the fuel economy of the California vehicles is nearly unchanged for the two model years. This is consistent with the calibration data listed in Table 5-32. The 1-mpg difference between the 49-states and California vehicle data is also small enough to be within the normal test error tolerance band.

5.10.4.9.2 Dasher Fuel Economy and Emissions

Figures 5-39 and 5-40 present three-year histories of fuel economy for the Dasher with either manual or automatic transmission. The 1974 data shown for California vehicles are also representative of vehicles sold in the 49-states as VW marketed cars certified to California standards in all states for 1974.

For both manual and automatic transmission vehicles, small 1974 to 1975 declines in fuel economy are shown in the subject figures. While these fuel economy changes are within error tolerance bands associated with fuel economy and emission tests, some justification for the decline is shown in the calibration data of Table 5-31. The richer 1975 versus 1974 carburetor setting is the only calibration change noted, and the decline in fuel economy may be attributed to this source.

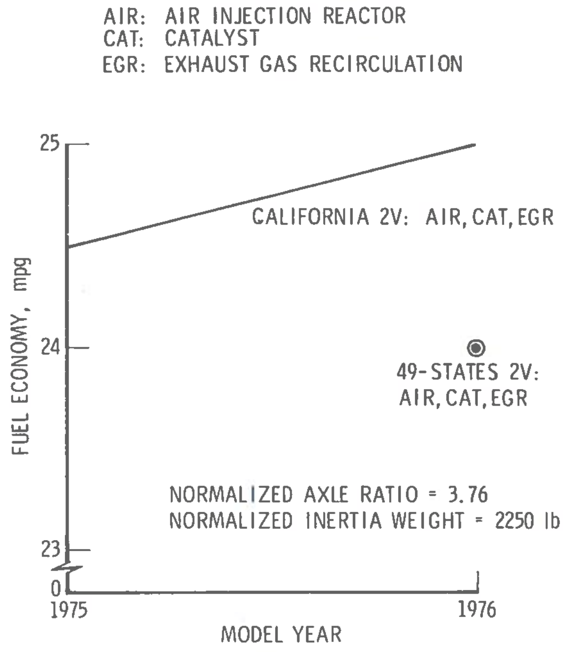


FIGURE 5-38. NORMALIZED AVERAGE CITY FUEL ECONOMY: VW 97- AND 89.7-CID ENGINES; RABBIT AUTOMATIC TRANSMISSION VEHICLE

Interestingly, the 1975 49-states version of the Dasher shown in Figures 5-39 and 5-40 exhibits the same fuel economy as the 1975 California Dashers even though it uses 3 deg less basic timing and 6 deg less vacuum advance at high vacuum levels. The lessened timing is a consequence of using only secondary air injection and having no EGR system, whereas in 1975 California Dashers use air, a catalyst, and EGR. While fuel economy does not

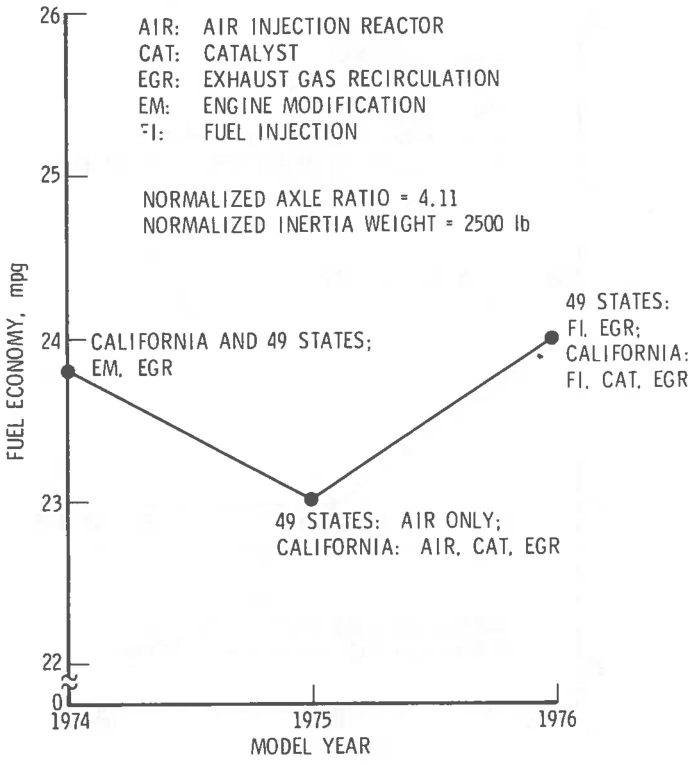


FIGURE 5-39. NORMALIZED AVERAGE CITY FUEL ECONOMY: VW 97- AND 89.7-CID ENGINE; DASHER MANUAL TRANSMISSION VEHICLE

suffer compared to California vehicles the 49-states cars have much higher emission levels as shown in Table 5-31.

Increasing fuel economy for the 1975 to 1976 model years is shown in all cases except for California automatic transmission vehicles. Again, all changes fall within test error tolerance bands. In any case, the change from a carburetor to fuel injection and attendant changes in the basic form of the EGR system as well as a year-to-year engine displacement change tend to obscure the effect calibration changes may have on fuel economy. However, the change to fuel injection in 1976 with its attendant capability for better fuel economy and suppression of emissions through more precise air/fuel ratio control likely has contributed to the observed economy improvement.

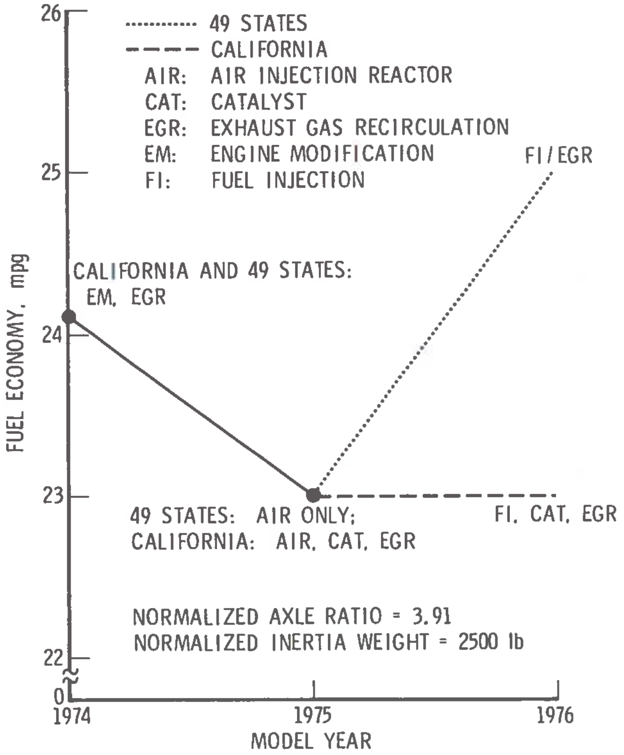


FIGURE 5-40. NORMALIZED AVERAGE CITY FUEL ECONOMY: VW 97- AND 89.7-CID ENGINE; DASHER AUTOMATIC TRANSMISSION VEHICLE

5.11 VOLVO

5.11.1 Engine/Vehicle Configurations

A 4-cylinder, in line, overhead valve engine of 121-CID is the unit chosen to typify the Volvo engine control practices. The engine is teamed with a two- and four-door sedan currently rated at 3000-pounds inertia weight and a station wagon rated at 3500-pounds. Three-speed automatic as well as four- and five-speed manual transmissions are offered.

Model years of interest for purposes of this report are 1970, 1974, and 1975. The 1976 model year is not included because Volvo has introduced a completely new overhead cam engine in 1976, which bears no relation to the engine selected for this study. Production of the unit selected was terminated at the end of the 1975 model year.

5.11.2 Engine Design Features

Table 5-33 provides a summary and overview of the subject engine for the 1970, 1974, and 1975 model years (Refs. 5-89 through 5-95 and 5-10). Adoption of continuous fuel injection in 1974 is the main distinguishing feature when compared to previous pulse modulated injection versions of the engine.

5.11.3 Volvo 121-CID Engine

5.11.3.1 Engine Modifications

A bathtub combustion chamber configuration with a 6.16 inch^{-1} surface area to volume ratio is used on the Volvo 121-CID engine. The compression ratio is 8.7:1 for 1974 and 1975, while in 1970 prior to institution of NO_x emission standards the compression ratio is set at 9.5:1, as shown in Table 5-33.

Valve timing has been standardized for manual and automatic transmission fuel-injected vehicles in 1975. Previously, in 1974 the models equipped with manual transmission used a slightly greater amount of valve overlap, equally divided between earlier intake valve opening and later exhaust valve closing.

5.11.3.2 Intake System

The intake air system used on the Volvo 1974 and 1975 fuel-injected engines is not thermostatically controlled. However, on vehicles using the pulse modulated fuel injection system a sensor in the air cleaner inlet provides a measurement of intake air temperature to the electronic control unit of the fuel injection system.

5.11.3.3 Fuel Injection Design Features

The fuel injection system introduced in 1974 and currently used with Volvo's 121-CID engine is the Bosch K-Jetronic CIS. However, earlier model year engines employ a Bosch time or pulse-modulated system. As the pulsed system is described in Section 5.8.5.2 covering the SAAB fuel injection system it is not repeated here. A description of the CIS follows.

TABLE 5-33. ENGINE SPECIFICATIONS: VOLVO 121-CID ENGINE

Engine Parameter	Model Year					
	1975		1974		1970	
	49 States	California	49 States	California	49 States	California
No. of Cylinders	4		4		4	
Bore, in.	3.5		3.5		3.5	
Stroke, in.	3.15		3.15		3.15	
Displacement, cu in.	121		121		121	
Surface/Volume, 1/in.	6.16		6.16		6.16	
Compression Ratio	8.7		8.7		9.5	
Cylinder Head Type	OHV		OHV		OHV	
Advertised HP at Engine Speed, rpm	98 at 6000	94 at 6000	109 at 6000	94 at 6000	120 at 6000	
Torque, ft-lb, at Engine Speed, rpm	110 at 3500	105 at 3500	115 at 3500	105 at 3500	-	
Exhaust System Type	Single		Single		Single	
Combustion Chamber Configuration	Bathtub		Bathtub		Bathtub	
Intake Valve Diameter, in.	1.73		1.73		-	
Intake Valve Lift, in.	0.284		0.284		-	
Exhaust Valve Diameter, in.	1.38		1.38		-	
Exhaust Valve Lift, in.	0.284		0.284		-	
Intake Valve Opens, deg BTC[a]	29		29 (A) (FI) 31 (M) (FI)		-	
Intake Valve Closes, deg ABC	71		71 (A) (FI) 73 (M) (FI)		-	
Intake Valve Duration, deg	280		280 (A) (FI) 284 (M) (FI)		-	
Exhaust Valve Opens, deg BBC	71		71 (A) (FI) 73 (M) (FI)		-	
Exhaust Valve Closes, deg ATC	29		29 (A) (FI) 31 (M) (FI)		-	
Exhaust Valve Duration, deg	280		280 (A) (FI) 284 (M) (FI)		-	
Valve Overlap, deg	58		58 (A) (FI) 62 (M) (FI)		-	
Distributor Type	Breakerless; centrifugal advance and vacuum retard		Breaker point; centrifugal advance		Breaker point	
Basic Ignition Advance, deg BTC, at Engine Speed, rpm	5 at 700		10 at 700		4 at 800	
Idle Speed, rpm[a]	850 (A) 900 (M)		850 (A) 900 (M)		900	
Fast Idle Speed, rpm	-		-		-	
Intake Air Temperature Control	Ambient		Ambient		Ambient	
Fuel System Type	Continuous FI		Continuous FI		Timed FI	
Fuel Metering Method	Fuel flow regulated by air flow		Fuel flow regulated by air flow		Timed injection regulated by air flow	
Enrichment Method	Temperature-regulated fuel pressure		Temperature-regulated fuel pressure		Temperature-regulated injection time	
Choke Type	Cold-start injection		Cold-start injection		Cold-start injection	
Carburetor Venturi Diameter, in.	-		-		-	
Carburetor Maximum Air Flow, cfm, at Intake Vacuum, in. Hg	160		170		-	
Emission Control Systems	AIR EGR EVAP FI PCV	AIR CAT EGR EVAP FI PCV	EGR EVAP FI PCV	EGR EVAP FI PCV	EVAP FI PCV	
Emission Control Devices	EGR defeat at idle and WOT CAT/EGR Inspect/replace warning light		EGR defeat at idle and WOT		-	

[a] A = automatic transmission; M = manual transmission

5.11.3.3.1 CIS Design Features

The CIS modulates fuel flow by regulating fuel flow rate to the injectors as a function of air flow in the intake manifold. The modulating mechanism consists of a circular air flow sensor plate positioned in a vertical air flow venturi and connected by a pivoted balanced lever arm to a fuel control plunger. Increased air flow through the venturi moves the sensor plate upward causing proportional movement of the lever arm, which in turn moves the fuel control plunger. Nominally constant system fuel pressure counteracts sensor plate movement via the plunger and is temperature-modulated during cold starts to provide mixture enrichment for cold engine operation as explained later.

Movement of the plunger progressively uncovers four fuel metering slots in the cylinder housing the plunger. Fuel under pressure at each metering slot flows through the area uncovered by the plunger and is then routed to the four injectors located in the intake manifold near each engine cylinder intake valve.

Four pressure regulating valves maintain a constant pressure drop across each metering slot. This in turn causes fuel flow through each slot to be proportional to the area uncovered by the plunger. Since plunger movement and uncovered metering area are proportional to air flow, fuel flow rate is also proportional to air flow. This results in a system capable of maintaining a constant air/fuel ratio over a wide range of engine speeds.

For off-idle operation, air flow to the engine is controlled by the driver via a throttle pedal connected to a throttle in the intake manifold. Idle air is provided via a throttle bypass passage, and additional idle air for a high-speed cold engine idle is provided by an auxiliary air valve which is controlled by a bimetallic spring. During engine warmup, the bimetallic spring is electrically heated, causing additional idle air to gradually decrease to zero at which time normal engine idle speed is attained.

A single cold start injector is used to enrichen the air/fuel mixture for engine temperatures below 95°F. The injection time is controlled by an electrically heated thermal time switch which provides extra fuel for as long as 12 seconds at -5°F. The injection time is decreased as a function of increasing engine temperature and goes to zero at 95°F. In all cases, the cold start injector is automatically switched off as soon as the engine starts.

Enrichment of air/fuel mixtures required for cold engine operation after engine startup is provided by a fuel control pressure regulator. The regulator is controlled by a bimetallic spring in a manner that decreases fuel pressure in the system for decreasing temperature. Since the air flow sensor plate movement is counteracted by fuel pressure, a decreased fuel pressure allows a larger sensor plate movement for a given air flow rate. This in turn results in an increased fuel flow rate and the desired mixture enrichment needed for cold engine operation. Enrichment is gradually diminished as the bimetallic spring is heated electrically and the system fuel pressure approaches its normal operating value.

5.11.3.3.2 Fuel Injection System Calibration

The fuel injection system calibration data provided by Volvo for the 1974 and 1975 model years are presented in Table 5-34, showing fuel flow rate versus air flow rate (Refs. 5-89 through 5-92). As indicated, the air/fuel ratio remains near 14-15 over the off-idle and part-throttle operating range of the engine. This air/fuel ratio has been selected by Volvo to meet the emission regulations in conjunction with the emission control systems and devices identified in Table 5-33.

5.11.3.4 Ignition System

5.11.3.4.1 Design Features

For 1975, Volvo uses a breakerless inductive ignition system consisting of a distributer, an electronic module, and an ignition coil. The distributer contains a permanent magnet stator, an armature, and a pickup coil. Operation is based on making and breaking a magnetic circuit between the rotating armature and fixed stator. Current pulses thus produced are sensed by the pickup coil and sent to the electronic module which opens and closes the primary side of the ignition coil, thereby inducing the required spark plug firing voltages in the coil secondary.

Prior to the 1975 model year, a conventional breaker-point ignition system is used on the subject engine.

5.11.3.4.2 Ignition Advance

For the model years shown in Table 5-33 Volvo uses only centrifugal advance. Vacuum control is limited to vacuum retard, which is used

TABLE 5-34. CERTIFICATION CALIBRATION DATA: VOLVO 121-CID ENGINE

Engine/Vehicle Parameter[a]	Model Year and Certification Standard												
	1975 49 States			1975 California			1974 49 States			1974 California		1972	1970
Vehicle Model	242	245	245	242	245	245	142	145	144	145	144	-	-
Transmission Type	M5	M4	A3	M5	M4	A3	M5	M4	A3	M4	A3	-	-
Vehicle Inertia Weight, lb	3000	3500	3500	3000	3500	3500	3000	3500	3000	3500	3000	-	-
Rear Axle Ratio	4.3	4.1	4.1	4.3	4.1	4.1	4.3	4.1	4.1	4.1	4.1	-	-
Catalyst	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No
Carburetor Calibration, A/F													
Idle: 0.8-lb/min air flow	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	-	-
Off Idle: 1.5-lb/min air flow	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	-	-
Part Throttle: 4.4-lb/min air flow	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	-	-
WOT at Max.: 11.8-lb/min air flow	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	-	-
Basic Timing, crankshaft deg BTC	5	5	5	5	5	5	10	10	10	10	10	10	4
Centrifugal Advance, crankshaft deg													
1000 rpm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
1500 rpm	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	11.0	7.0
2000 rpm	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.5	13.0
3000 rpm	26.0	26.0	23.0	26.0	26.0	23.0	19.0	19.0	19.0	19.0	19.0	24.0	25.0
4000 rpm	29.0	29.0	27.0	29.0	29.0	27.0	22.0	22.0	22.0	22.0	22.0	24.0	25.0
5000 rpm	28.0	28.0	28.0	28.0	28.0	28.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0
EGR Valve Calibration													
Signal Pressure to Open, in. Hg	1.6	1.6	1.6	1.0	1.0	1.0	1.6	1.6	1.6	2.0	2.0	-	-
Flow at 8-in. Hg, cfm	3.9	3.9	3.9	20.0	20.0	20.0	3.9	3.9	3.9	10.0	10.0	-	-
Fuel Economy, mpg													
City	16	16	17	16	16	17	17.5[b]	18.4[b]	16.1[b]	15.8[b]	16.1[b]	-	-
Highway	26	26	23	26	26	25	-	-	-	-	-	-	-
Exhaust Emissions, g/m													
HC	1.1	1.0	1.3	0.5	0.4	0.3	-	-	-	-	-	-	-
CO	10.0	9.0	15.0	3.4	3.6	6.8	-	-	-	-	-	-	-
NO_x	1.4	1.6	1.9	1.2	1.6	1.2	-	-	-	-	-	-	-

[a] Vacuum advance is not used

[b] 1974 FTP

in the 1970, 1972, and 1975 model years. Maximum retard is set at 5 engine crankshaft deg and is effective only at idle.

Table 5-34 presents engine calibration data and shows ignition advance for four model years. As may be seen, 49-states and California vehicles use the same ignition advance schedule; however, a small difference exists between schedules used on 1975 automatic as opposed to 1975 manual transmission vehicles. Generally, centrifugal advance shows a somewhat more rapid initial rise with engine speed in 1970 and 1972 than in the 1974 and 1975 model years. In addition, basic timing is reduced in 1975 from previous 1972 and 1974 levels.

5.11.3.5 Exhaust Gas Recirculation

The Volvo EGR system is based on utilization of intake venturi vacuum as a measure of total air flow to the engine. As this signal is too weak to actuate the EGR valve, a vacuum amplifier arrangement is used to provide the necessary vacuum. In addition, the system incorporates an accumulator to maintain an adequate source of vacuum for conditions of low intake manifold vacuum, which is the primary vacuum source for the system.

Two EGR override mechanisms are used. The first is implemented by a throttle switch and solenoid-operated valve which dumps the EGR vacuum signal to atmosphere when the throttle is at idle position. The second EGR override occurs whenever the magnitude of sensed venturi vacuum is equal to or greater than the magnitude of manifold vacuum. This allows the engine to develop full power by defeating EGR during full-throttle operation. In order to maintain adequate NO_x control during city driving, a 6-second delay is incorporated in the relief valve which implements the full-throttle override.

Table 5-34 presents EGR flow rates for the 1974 and 1975 model years. As seen, 49-states EGR rates remain unchanged from year to year, while California rates increase. In addition, the vacuum signal pressure required to open the EGR valve is lower on 1975 California vehicles than on their 1974 counterparts.

5.11.3.6 Secondary Air Injection

The Volvo secondary air injection system, introduced in the 1975 model year, is of conventional design and consists of a positive displacement engine-driven air pump, working in conjunction with a diverter valve and check valve. The system functions by delivering intake air, which is filtered centrifugally, to an air injection manifold via flexible hoses fitted to the output of the diverter valve. The diverter valve serves two functions. First, it acts as an antibackfire valve by momentarily diverting pump air flow to the atmosphere during engine deceleration. Its second function is to extend pump and exhaust system life by acting as a pressure relief valve which dumps the air pump output to atmosphere at a predetermined value to prevent pressure buildup and power consumption by the air pump. The purpose of the check valve is to preclude exhaust back flow damage to the hoses, diverter valve, and air pump.

5.11.3.7 Catalytic Converter

Volvo uses a catalytic converter to oxidize HC and CO on 1975 California vehicles. The system is implemented by a single muffler-like canister containing a platinum and palladium coated monolithic ceramic substrate. An odometer-actuated 15,000-mile inspection, 30,000-mile replacement warning light is incorporated in the vehicle instrument panel. This light also serves as an EGR inspection and replacement alert device.

5.11.3.8 Crankcase and Evaporative Emission Control

Standard positive crankcase ventillation and evaporative control systems are used with the Volvo 121-CID engine. Functional descriptions for these systems are presented in Section 3.

5.11.3.9 Fuel Economy and Emissions

Fuel economy and emission data (Refs. 5-10, 5-11, and 5-13) for the 1974 and 1975 49-states and California certification vehicles are listed in Table 5-34. The normalized average city fuel economy curves based on these data and the 1973 certification data listed in Ref. 5-20 are presented in Figure 5-41. The data shown are normalized for axle ratio and inertia weight according to the procedure described in Section 3. As indicated, the fuel economy of the 49-states vehicles equipped with a manual transmission decline between 1974 and 1975. This trend is well correlated with the calibration data shown in Table 5-34, which shows a decline in low-speed spark advance between 1974 and 1975 while EGR rates remain unchanged. The declining fuel economy shown between 1974 and 1975 for California vehicles with manual

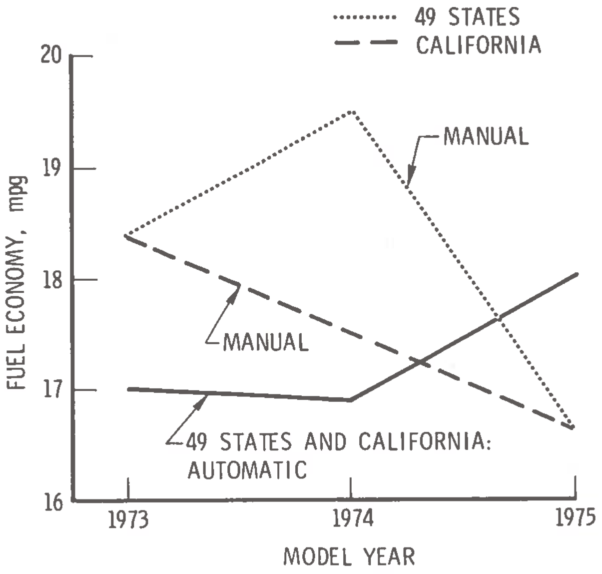


FIGURE 5-41. NORMALIZED AVERAGE CITY FUEL ECONOMY: VOLVO 121-CID ENGINE

transmission is well correlated with both spark timing and EGR flow rates as both fuel economy and spark timing decrease while EGR increases.

While the fuel economy difference between the 1974 model 49-states and California vehicles with manual transmission might be attributed to the higher EGR flow used in California, this rationale does not hold for 1975. Since an even larger difference in EGR rates exists in 1975, the apparent discrepancy in the normalized fuel economy of the 1975 California and 49-states vehicles appears to be the result of test-to-test and vehicle-to-vehicle variabilities.

Fuel economy trends of automatic transmission vehicles shown in Figure 5-41 are in opposition to the calibration data in Table 5-34.

While the fuel economy of 49-states and California vehicles increases between 1974 and 1975, the spark advance declines, particularly at low engine speeds. This occurs over a time period in which 49-states EGR rates remain unchanged and California EGR rates increase. Considering these calibration modifications, the observed rise in fuel economy is difficult to rationalize and is attributed to normal test and hardware variations.

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APPENDIX

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no innovation, discovery, improvement, or invention. However, this report presents a useful analysis of the vehicle emission control and fuel economy measures undertaken by selected vehicle manufacturers, both domestic and foreign.